INTERIM SALT CONTAMINATION ASSESSMENT & REMEDIATION GUIDELINES

Alberta
ENVIRONMENT

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1.0 INTRODUCTION

Environmental impacts from salt releases are often associated with activities such as oil and gas production, salt/sand processing and storage facilities at highway maintenance yards, rendering plants, runoff from snow removal dumps and the transportation of saline material for industrial. These salts can be very mobile and may easily move with water over the surface or down through soil. Typical environmental impacts associated with excess salt in soil and surface water or groundwater are:

- Degradation of soil chemical properties and impaired vegetation growth;
- Degradation of soil physical properties caused by excess sodium concentrations; and
- Degraded surface water or groundwater quality.

The most efficient and cost effective method of avoiding adverse effects and the attendant remediation costs associated with salt releases is spill prevention. When spills do occur, a fast, effective response based on a comprehensive understanding of impacts, salt movement, and assessment and remediation procedures can avoid or mitigate adverse effects on the environment.

The intent of this Guideline is to:

- Summarize regulatory requirements in Alberta, including salt remediation objectives;
- Develop awareness and understanding of the salt spill problem and the necessity for effective and complete remediation; and
- Provide an overview of effective site assessment and remediation procedures.

This document is designed to assist those involved in prevention, assessment, remediation and management of salt contaminated sites. Appendix A presents background information for those who desire a more complete understanding of industry sources of salt, saline/sodic soils, movement of salts in soil and groundwater, and adverse effects of salt on soil, vegetation and groundwater. A glossary is also provided.

2.0 REGULATORY CONSIDERATIONS

2.1 Environmental Protection and Enhancement Act

Remediation of salt-affected land must meet requirements of Alberta's *Environmental Protection and Enhancement Act* (Province of Alberta, 1992). The Act states the importance of preventing environmental impacts and the obligation of responsible parties to remediate areas adversely affected by a substance release (e.g. salt release). In order to meet these requirements, all the following conditions must be met:

- Contaminant concentrations must meet remediation objectives (background levels, generic guidelines or site-specific risk-based objectives) or better.
- Any residual contamination must not adversely affect current receptors or other potential receptors possible under the existing land use.
- Use and management of the affected area must not be any more limiting after remediation than before the spill.

Part 4, Division 1 of the *Environmental Protection and Enhancement Act* (Province of Alberta 1992) addresses ARelease of Substances Generally". Releases of saline material would be included in these provisions. Some of the issues addressed by subsections 97 to 104 include:

- Prohibition of release of substances exceeding approvals or regulations;
- Unauthorized release of substances that may cause adverse affects;
- Duty to report a release;
- Manner of reporting a release;
- Duty to take remedial measures;
- Issuance of environmental protection orders and emergency environmental protection orders regarding a release; and
- Emergency measures that may be taken.

The *Release Reporting Regulation* (Alberta Regulation 117/93, Province of Alberta, 1993a, as amended) includes subsections on substances governed by federal acts, substance release reports, and exemptions from reporting.

Under Alberta's *Environmental Protection and Enhancement Act* the guiding principles for industrial activities and remediation efforts are:

1. Prevention, and mitigation if necessary, of adverse effects caused by the release of substances into the environment (Part 4, Release of Substances); and
2. Conservation, and reclamation if necessary, of equivalent land capability for specified lands (Part 5, Conservation and Reclamation; *Conservation and Reclamation Regulation*; Province of Alberta, 1993a).

In the *Environmental Protection and Enhancement Act*, adverse effect is defined as:

> "Impairment of, or damage to, the environment, human health or safety or property."

Equivalent land capability is defined in the *Conservation and Reclamation Regulation* as;

> "The ability of the land to support various land uses after conservation and reclamation, similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical."

To be consistent with the guiding principles of the Environmental Protection and Enhancement Act, levels of contaminants must be returned to guideline levels or must produce no adverse effects on potential receptors.

2.2 Role of the Energy and Utilities Board

The Energy and Utilities Board Information Letter 98-2 (EUB, 1998b) sets out the division of responsibilities between the Board and Alberta Environment in the regulation of reclamation at upstream oil and gas facilities. The Energy and Utilities Board regulates the operation of upstream oil and gas facilities and the management of oilfield wastes such as excavated contaminated soil, sludges, and produced water. Alberta Environment is responsible for reclamation, setting soil and groundwater remediation objectives, overseeing in-situ remediation, risk assessment and risk management programs, and ensuring owners and operators decontaminate affected land.

2.3 Notification Requirements

2.3.1 Releases from Upstream Oil and Gas Facilities

A Memorandum of Understanding Between Alberta Environment and the Alberta Energy Utilities Board [*EUB Informational Letter 98-1* (EUB 1998a)] details the role of each agency in release notification. This document provides information on:

- When the upstream oil and gas industry is expected to report substance releases;
- To whom industry should report; and
- Form of the reporting (e.g. written vs. oral).

The document addresses past cumulative releases, new spills/releases/pipeline breaks, and flaring. Alberta Environment and the Energy Utilities Board both have substance release notification requirements for the upstream oil and gas industry (including pipelines) and have a role to play in the regulatory response to such release incidences. The agreement provides a reporting procedure for industry with an integrated Aone-window≅ approach and ensures that consistent notification and reporting requirements are in place for industry. It aims to ensure a coordinated and integrated response to complaints or emergencies between the regulatory agencies. Attachment 1 of the document specifies the primary contact for different releases associated with joint Alberta Environment/Energy and Utilities Board approved facilities or pipelines, or Energy and Utilities Board only approved facilities or pipelines.

2.3.2 Other Releases

The *Environmental Protection and Enhancement Act* and the *Release Reporting Regulation* (Alberta Regulation 117/93 as amended) address the release of substances into the environment and set out requirements for the reporting of releases to Alberta Environment. The *Release Reporting Guidelines* (Alberta Environment, 1995b) clarify Alberta Environment's interpretation of those documents, in view of the broad range of interpretation and reporting obligations.

The *Release Reporting Guidelines* address:

- Who must report;
- What must be reported; and
- When to report a release.

2.4 Remediation Objectives

There are two basic approaches used in Alberta to determine remediation objectives for a specific site. The **Criteria or Guideline Based Approach** involves direct adoption of accepted soil remediation guidelines. **The Risk Assessment Approach** involves an evaluation of the exposure potential and hazard to receptors and the resulting risk to receptors of adverse effects.

2.4.1 Generic Guidelines

Alberta Environment makes use of generic guidelines to determine the need for remediation in order to prevent adverse effects (Table 2.1). Although Alberta Environment estimates that these guidelines set a satisfactory level of protection in most cases, site specific instances may exist where the generic guidelines do not ensure an equivalent land capability. For example, market gardens growing salt-sensitive crops such as beans or strawberries may require remediation to more stringent objectives. **In such cases Environmental Protection and Enhancement Act requirements for reclamation to equivalent capability take precedence over the generic guidelines**. If future changes in land use lead to adverse effects because of increased sensitivity to contaminants, the Environmental Protection and Enhancement Act requires mitigation of those effects.

Table 2.1 Generic Guidelines for Salt Contaminated Soil

Generic Guidelines for Salt Contaminated Soil*	Comments
Soil Quality Relative to Disturbance and Reclamation (adapted from Alberta Agriculture 1987)	The primary guidelines for assessing salt and sodium status of salt contaminated soil preferred by Alberta Environment are adapted from the "Soil Quality Criteria Relative to Disturbance and Reclamation". These guidelines were developed to provide physical, chemical, and biological guidelines for evaluation of the suitability of soil materials for revegetation. Application of the guidelines requires comparison with representative off-site controls. See Table 2.2.
Canadian Council of Ministers of the Environment Commercial/Industrial Criteria (CCME 1991)	"CCME Industrial/Commercial Criteria" for EC and SAR may be used at sites zoned for industrial use. See Table 2.3.

* The Canadian Environmental Quality Guidelines (CCME 1999) can be used in considering the water quality of salt affected water. See Table 2.4.

Remediation to the generic guidelines levels is expected for topsoil and subsoil, to a depth sufficient to prevent impact on the rooting zone, or to a depth at which similar levels of naturally occurring salts occur in the control soils. Efforts should also be made to remediate soil below this depth to generic guideline levels. If remediation of soil at depth is not feasible, a risk assessment approach is necessary.

Soil Quality Criteria Relative to Disturbance and Reclamation

The values of EC and SAR in Table 2.2 for any salt contaminated soil are considered acceptable when the rating category for both is equivalent or better than the salinity and sodicity ratings of a similar non-contaminated layer at a nearby representative, control location. If both contaminated soil and background controls are in the unsuitable category, site levels must be remediated to background levels or lower. Comparisons with control soils must be representative; i.e. comparisons with controls should be between soils in similar topographic positions, similar horizons, similar depths and of similar soil series classification.

Table 2.2 Soil Quality Criteria Relative to Disturbance and Reclamation

Parameter		Rating Categories			
		Good	Fair	Poor	Unsuitable
Topsoil[c]	EC dS/m (salinity)	<2[a]	2 to 4	4 to 8	>8
	SAR (sodicity)	<4	4 to 8	8 to 12	>12[b]
Subsoil[c]	EC dS/m (salinity)	<3	3 to 5	5 to 10	>10
	SAR (sodicity)	<4	4 to 8	8 to 12	>12

a Some plants are sensitive to salts at EC < 2 dS/m (e.g. flax, clover, beans, wheat, peas, some garden crops).

b Material characterized by SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

c Topsoil: surface A horizons on the control area, or the equivalent surface soil on the reclaimed site.
Subsoil: B and C horizons and the upper portion of the parent material.

Canadian Council of Ministers of the Environment Commercial/Industrial Criteria

For sites that have an industrial land use and are zoned industrial by the local zoning authority, Commercial/Industrial Criteria from the Canadian Council of Ministers of the Environment (CCME) *Interim Canadian Environmental Quality Criteria for Contaminated Sites* (Table 2.3) are acceptable. In using these guidelines, the proponent incurs the liability of restricting the future land use to commercial/industrial; if zoning changes to a more sensitive land use in the future, further remediation may be required.

Table 2.3 CCME Commercial/ Industrial Soil Criteria

Parameter	CCME C/I Soil Criteria
EC	4 dS/m
SAR	12

Generic Water Quality Guidelines

The *Canadian Environmental Quality Guidelines* (CCME, 1999) lists maximum allowable levels for various water chemistry parameters for water uses including drinking water, freshwater aquatic life, agricultural uses (including livestock watering), recreational use and industrial use. Selected maximum acceptable water concentration guidelines relevant to salt contamination are summarized in Table 2.4. Because nitrates may be added to sites in the form of a calcium nitrate amendment as part of a remediation treatment, maximum acceptable concentrations for nitrates in water are also listed.

Table 2.4 Selected Canadian Water Quality Guidelines

Water Use	Parameter
Drinking Water	• Chloride – 250 mg/l • Total dissolved solids – 500 mg/l • Nitrate (as N) – 10 mg/l • Nitrite (as N) – 1 mg/l (where nitrates and nitrites are both present, the total acceptable concentration is 10 mg/l)
Livestock Watering	Total dissolved solids – 3000 mg/l[a] 100 mg/l for nitrate plus nitrite, and 10 mg/l for nitrite alone

[a] Water with higher TDS concentrations can be used but other factors should be taken into consideration (e.g. type of livestock, age, reproductive state). See CCME (1999).

2.4.2 Development of Site Specific Guidelines

2.4.2.1 Site-Specific Risk Assessment

The generic guidelines are based on the well-understood environmental impacts of salt and sodium within the root zone or water source. Risk assessment may be used as an alternative to generic guidelines for situations such as those in which:

- Guideline-based objectives are not appropriate given the site-specific exposure conditions; or
- Significant or sensitive receptors of concern have been identified.

Under such circumstances, risk assessment may be used to: (1) to develop site-specific guidelines; or (2) to develop a risk management approach that leaves contaminants in place but prevents or mitigates receptor exposure. In situations where risk management is used, it may be necessary to impose restrictions on future land or ground/surface water use in order to mitigate adverse effects.

The risk assessment approach is based on an evaluation of exposure and hazard potential at a particular site. Alberta Environment (Regional Offices, Environmental Service) should be involved as early as possible when undertaking a risk assessment.

2.4.2.2 Risk Management Approach

If the site assessment indicates that there is an adverse and unacceptable effect on the environment, the proponent may choose to remediate to generic or equivalent site-specific guidelines. Alternatively, the proponent may implement a risk management strategy that will manage the salts in place in such a manner that the risk of adverse effects is minimized. The application of a risk management approach involves an on going responsibility to monitor and maintain the site and communicate with the landowner. Salts left in place may have an impact on future land use; the proponent must accept long-term liability for subsurface contamination left in place. Because salts can leach into groundwater, this liability extends to potential future impacts on groundwater resulting from leaching of salts from soil.

Regulatory acceptance of the risk management approach is contingent on landowner acceptance. In addition, either the proponent must maintain control of the site or the proponent must obtain the landowner's agreement to manage the site appropriately. The proponent must also demonstrate (in the risk assessment) that the site boundaries defined are appropriate (e.g. that the impacts from future leaching and migration of salts have been considered). Prevention of adverse effects may depend on the landowner's diligence in maintaining any restrictions on future uses of the land or water. Alberta Environment will not issue a letter of compliance in these cases. Rather, the correspondence will indicate the on-going responsibility of the relevant parties to maintain the necessary management controls. However Alberta Environment can document the obligations of the parties involved and indicate the acceptability of any conditions, with the provision that the conditions are maintained for as long as the contamination remains on the property. Information on contamination remaining and any resultant restrictions must be recorded in any applications that request any certification from Alberta Environment.

2.5 Regulatory Closure

Upon submission to Alberta Environment (Regional Office, Environmental Service) of adequate verification that the site meets regulatory requirements, Alberta Environment can issue a Closure Letter for the site. This letter is not required by regulations but is desired by some landowners and operators to indicate that remediation has been carried out successfully and has met regulatory requirements. It does not release operators from future liability of contamination associated with the site. Although not required, the letter can also be included as part of a Reclamation Certificate Application.

2.6 Additional Salt Contamination Related Regulatory Documents

Table 2.5 lists the documents that are most relevant to the regulatory issues associated with salt (and other) contamination. Any individual or group that may become involved with assessment and/or remediation of salt contaminated sites should obtain the relevant documents. Sources for these and other regulatory documents are listed in Table 2.6.

Table 2.5 Salt Contamination Related Regulatory Documents

Document	Description
Alberta Soil Criteria Relative to Disturbance and Reclamation (Alberta Agriculture, 1987)	Criteria for evaluating suitability of undisturbed and reconstructed soils for revegetation. Values for salt related (and other) soil properties are classed into suitability groups (good, fair, poor, unsuitable); these properties include electrical conductivity (EC), and sodium adsorption ratio (SAR). Suitability rating for on-site soils should be the same as that for off site soils after remediation.
Canadian Council of Ministers of the Environment Interim Canadian Environmental Quality Criteria for Contaminated Sites (CCME, 1991)	The CCME remediation guidelines for soil are accepted by Alberta Environment for sites under industrial land use, which are zoned industrial by the local zoning authority. These CCME Commercial/Industrial criteria include EC (4 dS/m) and SAR (12). Criteria for other inorganic elements are also given, but do not include chloride.
Canadian Environmental Quality Guidelines (CCME 1999)	This document addresses acceptable quality for air, water (drinking water supply, recreational water quality and aesthetics, freshwater aquatic life, and agricultural uses), sediment (freshwater and marine), soil (agricultural, residential/parkland, commercial, and industrial), and tissue residues.
Energy and Utilities Board Guide 50 Drilling Waste Management (EUB, 1996a)	This document represents a "Best Available Technology" approach to drilling waste management options and receiving soil contaminant loading guidelines. It covers disposal methods and information requirements. Most of the methods involve some salt related analyses and calculations of waste or receiving soil. These analyses may include chloride concentration, total chlorides, total sodium, electrical conductivity, sodium adsorption ratio, total dissolved solids, etc.
Energy and Utilities Board Guide G-51 Injection and Disposal Wells (EUB, 1994)	Addresses requirements for disposal wells and injection of brine.
Energy and Utilities Board Guide 55 Storage Requirements for the Upstream Petroleum Industry (EUB, 1995)	Any material, including produced (saline) water, drilling fluids, and oilfield wastes, that could adversely affect the environment and is produced, generated, or used by the upstream petroleum industry must be stored in accordance with these requirements.

Table 2.5 Salt Contamination Related Regulatory Documents (continued)

Document	Description
Energy and Utilities Board Guide 58 Oilfield Waste Management Requirements for the Upstream Petroleum Industry (EUB, 1996b)	This comprehensive document addresses oilfield waste requirements for the Energy and Utilities Board. Relevant issues addressed include: • Reportable oilfield wastes; • Assessment of wastes and sites for land farming and biopiles; • Requirements for site assessment and groundwater protection, wastes banned from disposal via injection into pipeline systems; • Waste manifesting (if saline contaminated material is mixed with dangerous oilfield waste); • Design and operation of oilfield waste facilities, performance standards for oilfield landfills; • Surface facilities associated with disposal wells; • Spreading oily by-products to roads; • Recommended analytical methods and Energy and Utilities Board waste classification.
Energy and Utilities Board IL 98-2 Suspension, Abandonment, Decontamination, and Surface Land Reclamation of Upstream Oil and Gas Facilities (EUB 1998b)	Describes the Alberta Environment and Energy and Utilities Board jurisdictional responsibilities for the steps involved in suspension, abandonment and reclamation of upstream oil and gas facilities. Energy and Utilities Board is responsible for suspension, abandonment and treatment and disposal of oilfield waste. Alberta Environment is responsible for remediation objectives and in-situ remediation.
Energy and Utilities Board IL 99-5 The Elimination of the Surface Release of Produced Water. (EUB, 1999)	This Information Letter bans the practice of releasing produced water to well-site surfaces and requires that centralized blowdown pits receiving produced water must conform with Guide 55.
Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation (Alberta Environment, 1994)	Summarizes generic guidelines applicable to soils under sensitive land uses in Alberta.
Guideline for Monitoring and Management of Soil Contamination Under EPEA Approvals (Alberta Environment, 1996)	This Alberta Environment document provides background and soil management program requirements for soil monitoring programs at facilities that hold operating approvals under the Environmental Protection and Enhancement Act in cases where substances may be released to soil. It does not strictly apply to other facilities where substances may be released to soil, although many of the principles in the guideline are relevant to them as well. This document accompanies the Soil Monitoring Directive.
Reclamation Criteria for Wellsites and Associated Facilities - 1995 Update (Alberta Environment, 1995a)	It is stated in this document that all contamination must be treated prior to application for certification. This includes salt contamination.

Table 2.6 Sources of Contaminant Related Regulatory Documents

• Environmental Protection and Enhancement Act • Alberta Release Reporting Regulation • Alberta Conservation and Reclamation Regulation	Queens Printer Publication Services 11510 Kingsway Edmonton, AB T5G 2Y5 Phone: (780) 427-4952 OR Queens Printer Publication Services McDougall Centre 455 – 6 St. SW Calgary, AB T2P 4E8 Phone: (403) 297-6251
• Guideline for Monitoring and Management of Soil Contamination Under EPEA Approvals • Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation • Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update	Alberta Environment Environmental Sciences Division 4th Floor, 9820 - 106 St. Edmonton, AB T5K 2J6 Phone: (780) 427-5883
• Release Reporting Guideline	Alberta Environment Enforcement and Monitoring Division 11th Floor, 9820 - 106 St. Edmonton, AB T5K 2J6 Phone: (780) 422-2560
• Canadian Council of Ministers of the Environment Interim Canadian Environmental Quality Criteria for Contaminated Sites • Canadian Council of Ministers of the Environment Canadian Environmental Quality Guidelines	Canadian Council of Ministers of the Environment Environment Secretariat 326 Broadway, Suite 400 Winnipeg, Manitoba R3C 0S5 Phone: (204) 948-2090
• EUB Guide 58 Oilfield Waste Management Requirements for the Upstream Petroleum Industry. • EUB Guide 50 Drilling Waste Management • EUB Guide 55 Storage Requirements for the Upstream Petroleum Industry • ERCB (EUB) Guide G-51 Injection and Disposal Wells • EUB IL 99-5 The Elimination of the Surface Release of Produced Water • EUB IL 98-1 A Memorandum of Understanding Between Alberta Environmental Protection and the Alberta Energy Utilities Board Regarding Coordination of Release Notification Requirements and Subsequent Regulatory Response. • EUB IL 98-2 Suspension, Abandonment, Decontamination, and Surface Land Reclamation of Upstream Oil and Gas Facilities	Alberta Energy and Utilities Board Information Services 640 - 5 Ave. SW Calgary, AB. T2P 3G4 Phone: (403) 297-8190
• Alberta Soil Criteria Relative to Disturbance and Reclamation	Alberta Agriculture Conservation and Development Room 206, 7000 - 113 Street Edmonton, Alberta T6H 5T6 Phone: (780) 422-4385

3.0 SITE ASSESSMENT AND REMEDIATION PROCEDURES

Specific procedures undertaken to assess and remediate salt-affected sites are under control of the responsible party. However, Alberta Environment requires that these procedures, and the information submitted to Alberta Environment for review, follow a common approach.

The main steps involved in assessment and remediation of sites contaminated by salt are:

- Conduct site assessment, including a capability assessment (see Glossary) of control areas
- Determine remediation objectives
- Conduct risk assessment (if necessary)
- Develop remediation plans
- Conduct remediation
- Verify remediation

Alberta Environment expects environmental site assessments to adhere to accepted principles such as those presented in the Canadian Standards Association's *Phase 1 Environmental Site Assessment* document (CSA 1994). The main principles are:

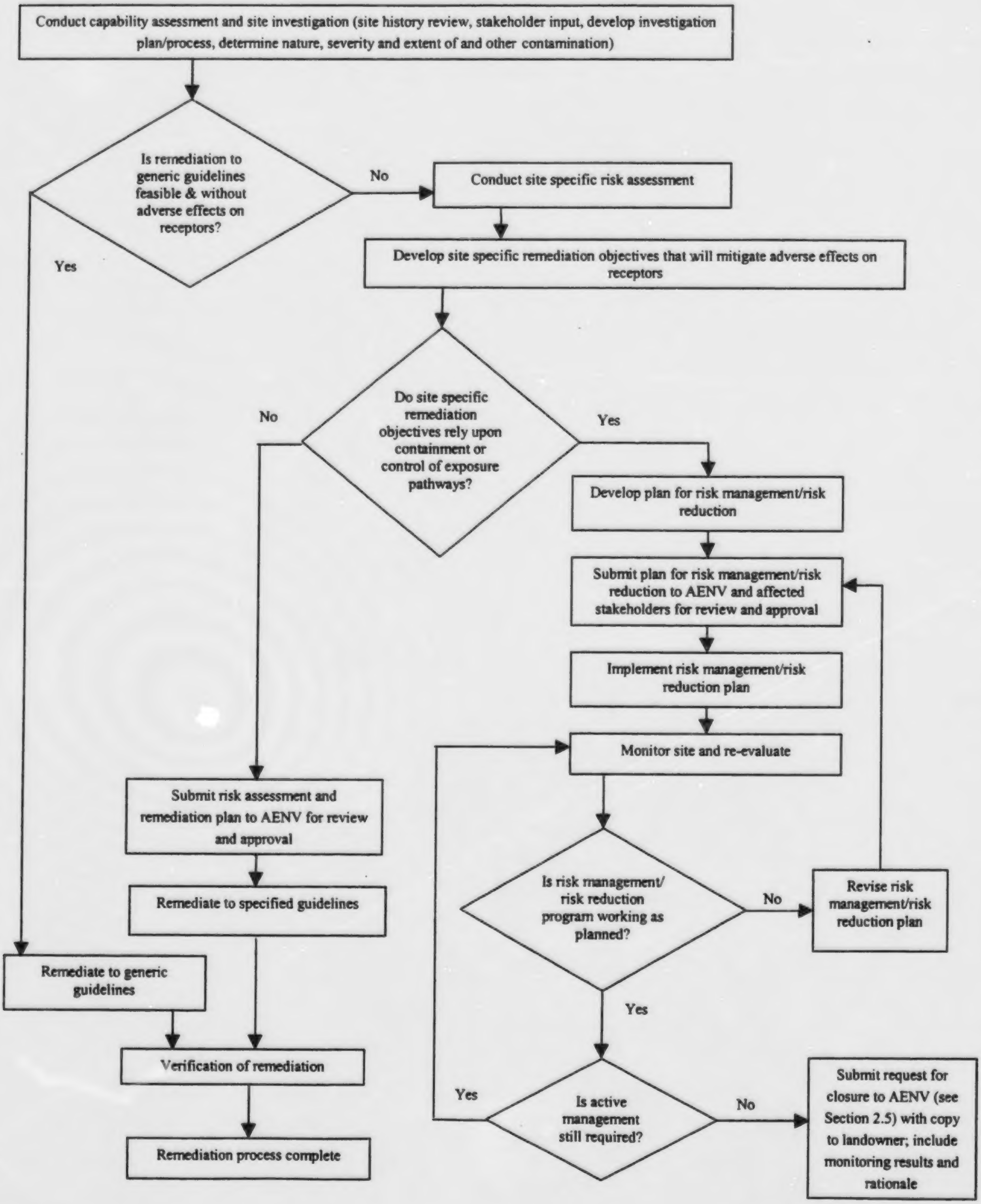
- Use competent, objective, independent assessors;
- Determine an appropriate level of assessment;
- Use logical and systematic procedures to gather information;
- Disclose any conflict of interest; and
- Assessor must execute due care, diligence, and judgement.

An overview of the site assessment and remediation process is provided in Figure 3.1.

3.1 Site Assessment

The assessment must characterize the site, delineate the nature and extent of the salt contaminated area, identify other contaminants (e.g. sterilants, hydrocarbons) that may also require management, and describe adverse effects and environmental impacts (e.g. reduced plant growth, water repellency). This may require several assessments over a period of time. The nature of an individual assessment depends on the objectives of that assessment. Typical tools used in a site assessment include:

Figure 3.1 Overall Assessment and Remediation Process Flow Chart


Conduct capability assessment and site investigation (site history review, stakeholder input, develop investigation plan/process, determine nature, severity and extent of and other contamination)
Is remediation to generic guidelines feasible & without adverse effects on receptors?
No
Yes
Conduct site specific risk assessment
Develop site specific remediation objectives that will mitigate adverse effects on receptors
Do site specific remediation objectives rely upon containment or control of exposure pathways?
No
Yes
Develop plan for risk management/risk reduction
Submit plan for risk management/risk reduction to AENV and affected stakeholders for review and approval
Implement risk management/risk reduction plan
Monitor site and re-evaluate
Submit risk assessment and remediation plan to AENV for review and approval
Remediate to specified guidelines
Is risk management/ risk reduction program working as planned?
No
Revise risk management/risk reduction plan
Yes
Remediate to generic guidelines
Verification of remediation
Remediation process complete
Yes
Is active management still required?
No
Submit request for closure to AENV (see Section 2.5) with copy to landowner; include monitoring results and rationale

- Background information from Energy and Utilities Board and operator records and landowner reports (e.g. site history, spill volume, etc.)
- Aerial and ground photographs
- Topographic maps
- Soil survey maps and reports
- Site capability assessment (i.e. control vs. site)
- Surficial geology characterization
- Visual indicators of spill (e.g. stressed vegetation, etc.)
- Geophysical techniques
- Sampling program for site and control area (soil/groundwater/surface water)
- Field and laboratory Analyses

Adequate site assessment and characterization are important for optimizing the efficiency and success of planning and carrying out remediation. It is necessary to consider possible adverse effects of a spill on surface and subsurface soils, groundwater, surface water, and associated biota. The quantity and quality of information required is specific to each site. Therefore, the guidelines provided here must be applied as appropriate to a specific field situation. Spill sites will often require surface and subsurface investigations to be conducted in several stages. Figure 3.2 illustrates the site assessment process. The first step is to collect background information. Based on that information, a plan for site investigation can be made.

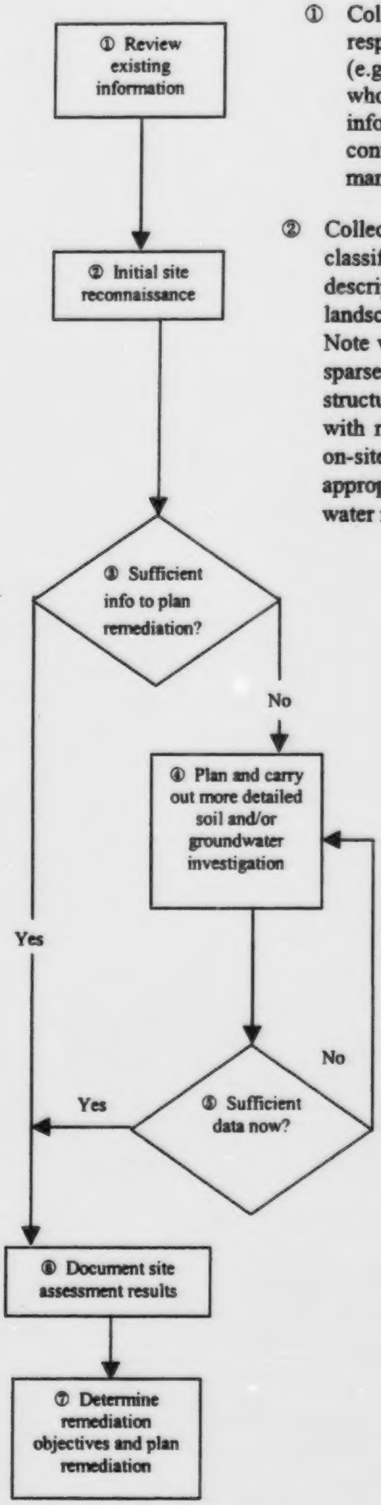
3.1.1 Background Information

Background information may come from various sources, including:

- the company responsible for the site,
- regulatory agencies,
- landowners or land managers (Crown Lands)
- published data (e.g. soil survey maps),
- air photographs, and
- companies/consultants/land agents who have previously worked on the site.

Spill information such as date, volume, extent, chemical composition, spill containment and recovery measures, remediation measures, and other management practices is of particular relevance. Table 3.1 lists types of background information useful in planning assessment and remediation.

Figure 3.2 Capability Assessment and Site Investigation Flow Chart


① Review existing information
② Initial site reconnaissance
③ Sufficient info to plan remediation?
No
Yes
④ Plan and carry out more detailed soil and/or groundwater investigation
No
Yes
⑤ Sufficient data now?
⑥ Document site assessment results
⑦ Determine remediation objectives and plan remediation

① Collect background information and site history from the company responsible for the site, regulatory personnel, landowners, published data (e.g. soil maps), air photographs, other companies/consultants/land agents who have previously worked on the site, etc. Obtain available spill information, such as date, volume, extent, chemical composition, spill containment and recovery measures, remediation measures, and other management practices.

② Collect site and control information on capability, soil characteristics (e.g. classification at soil series level, drainage class, slope, aspect, full pedon description), land use, groundwater, surface water, climate considerations, landscape characteristics, surface geology and any other relevant information. Note visual indicators of spill severity and extent, including stressed, stunted or sparse growth, dominance of salt-tolerant species, surface crusting, degraded soil structure, visible spill patterns on snow or soil, etc. Carry out initial delineation with reconnaissance geophysical survey (use to focus sampling effort), initial on-site field test analysis, and soil and water sampling for laboratory analysis as appropriate. Assess for other contaminants such as hydrocarbons, sterilants, water repellency, gas migration, etc.

③ Is there sufficient information to assess adverse effects and plan remediation? Has spill been adequately delineated both horizontally and vertically in the soil, groundwater and/or surface water? Except for very small, simple spills it is unlikely that sufficient information has been collected in the initial site reconnaissance and more sampling and analysis will be necessary.

④ Conduct investigation as required:

- Additional detailed visual inspection of soil and vegetation on site and control
- Additional soil sampling
- Additional soil field and laboratory testing
- Groundwater sampling and testing, observation wells
- Additional geophysical investigation
- Additional characterization of control area, spill site area, boundaries and hot spots

⑤ Is there now sufficient information to assess extent and severity of spill and proceed with determination of remediation objectives, and planning remediation?

⑥ Document results of all findings including background information, initial site inspection, and more detailed soil and groundwater assessments.

Table 3.1 Types of Background Information

Land Use	• Facilities, including buildings, pipelines and tanks • Excavations, trenches, berms, etc. • Other underground structures • Surface condition: gravel, asphalt, cement and surface stones • Roads, access to site • Surrounding land use: type, distance and direction • Land use of impacted area (on and off site; e.g. crop, market garden, orchard, bush pasture; any particularly salt sensitive vegetation, forest, wetlands, etc.) • Ownership (Public vs. Private Land)
Groundwater	• Existing wells: distance, direction, use and ownership (information can be obtained from the Alberta Environment Groundwater Information Centre) • Depth to usable aquifer in area (if available) • Evidence of groundwater discharge to surface water bodies • Major subsurface flow direction (if available)
Surface Water	• Surface runoff flow patterns • Surface water bodies: distance and type • Nearby users of water
Landscape	• Topography: terrain description (hummocky, level, etc.), slope gradient and slope position of contaminated area • Surface Drainage (near surface subsurface drainage may be apparent as well) • Existing erosion; erosion potential • Vegetation: type, density (annual crops), cover (perennial vegetation), frequency (trees and shrubs), and health
Surficial Geology and Soil	• Nature of the surficial deposits • Nature of the soils (e.g. soil series classification, drainage class, slope, aspect) • Depth to bedrock and type of bedrock
Other Site Conditions	• Conditions requiring special attention: sensitivity for wildlife, susceptibility to erosion, steep slopes, proximity to surface water, proximity to human or livestock drinking water supply, etc. • Season (winter, summer), weather (rainy, dry)
Historical and Other Information	• Spill information: date, volume, chemical composition, spill containment and recovery measures, if any, and observed effectiveness, remediation measures implemented, other management practices (by landowner: tillage, fertilizer, cropping, etc.), regulatory agency documentation, landowner concerns, previous spills in the area, etc. • Previous environmental monitoring, management and remediation in the area • Availability of local reclamation/remediation contractors, equipment (Bobcats, cultivators, seeders, subsoilers, etc.), amendments (straw, hay, manure, gypsum, etc.)

3.1.2 Site Assessment Plan

An important objective of a site investigation is to determine the nature and extent (horizontally and vertically) of salt contamination. During the site reconnaissance and the detailed investigation, information on the *spill site* and surrounding *control area* should be collected and compared. This information is especially important with salt spills, because naturally occurring saline and sodic soils may be present in the area. Control areas for comparison should be located near the spill site. Control sites should be free from contamination and should be representative of the soil, topography, slope and position along slope, aspect, and surface and internal drainage of the spill site.

The assessment plan should include some or all of the following:

- Field equipment required: for example:
    - hand sampling equipment (e.g. shovel, hand auger, trowel),
    - power sampling equipment (e.g. auger rig (solid stem or hollow stem augers), rotary rig, air hammer, backhoe),
    - field screening tools (e.g. portable EC meter, Quantabs®)
    - geophysical equipment,
    - camera (photographs are important for documentation of pre and post remediation site conditions and for documentation of remediation procedures);
- Geophysical survey strategy;
- Proposed borehole locations and patterns in salt-contaminated and control areas;
- Proposed location, design and construction of groundwater monitoring wells;
- Soil monitoring and sampling strategy;
- Groundwater monitoring and sampling strategy;
- Samples to be preserved and laboratory analyses to be carried out;
- Quality assurance and quality control program; and
- Personnel and public health and safety requirements.

It may not be necessary to use sampling and laboratory analysis to initially delineate the spill. It may be possible to delineate the spill using vegetation indicators, geophysical (EM31/EM38/resistivity) readings, field analysis, or surface characteristics. The initial delineation can then be used as a basis for soil sampling. Soil samples are then submitted to the laboratory for analysis. Once the types, amounts, pathways and extent of salt present are determined, a remediation program can be designed.

Site Assessment Procedure

3.1.3.1 Visual Indicators of Salt Contamination

Observations of soil properties, vegetation, snow and other characteristics can help to delineate the spill site. Signs of stress on vegetation include sparseness, stunted growth and other drought stress-like symptoms. At older sites, salt tolerant species may dominate the salt-affected area (see Appendix A4.2 for examples). If germination is poor, but older vegetation is living, it is likely that only the upper few centimetres are contaminated. If seedlings germinate but grow poorly or die off after roots extend downwards, contamination is likely deeper. Where vegetation is present, the depth of the root system may indicate the depth at which salt contamination is severe enough to prevent further root penetration.

Examples of plants which are most sensitive to salt include trees/shrubs (spruce, fir, cottonwood, aspen, birch, raspberry), field crops (field beans and peas, flax, sunflower, some wheat varieties), forages (timothy, red and alsike clovers), and garden crops (sweet corn, potatoes, carrot, onion, peas, etc.). Note that some of these may be adversely affected at salt levels below the *lowest* generic guideline levels (EC = 2 dS/m).

Soil indicators of salt that may be present include visible salt crystals, degraded surface soil structure and surface crusting, shiny dark coloured surfaces of soil aggregates, non-frozen soil where non-contaminated soil is frozen, and highly rusted pieces of metal. At recent spill sites, patterns left in the snow may reveal the extent of the spills.

3.1.3.2 Geophysical Tools

A number of geophysical tools can be used to make indirect measurements of salinity. The most commonly used of these are inductive electromagnetic (EM) meters. A number of EM meters are available including the EM-38 and EM-31, which are operated at or near the ground surface. All meters detect electrical conductivity differences in subsurface materials. They generate an electromagnetic field that passes through the soil, giving a bulk electrical conductivity (EC) value. The EM-38 measures apparent conductivity of the ground to a depth of about 1.5 m in the vertical dipole mode, and to a depth of about 0.75 m in the horizontal dipole mode. The EM-31 measures apparent conductivity to a depth of about 6 m in the vertical dipole mode. The response of the EM meter is largely influenced by soil salinity, but also, to a lesser extent, by soil temperature, soil moisture and soil texture. Pipelines, overhead wires, other metals, and electrical fields may interfere with results. Electrical resistivity surveys may also be used to delineate salt contaminated areas. The geophysical survey area should include the spill area and should extend well into the surrounding non-contaminated area to adequately characterize both spill and non-spill (background control) areas. Further information on EM equipment can be obtained from a number of sources including VanderPluym and Harron (1992), McNeill (1992) and CCME (1994).

Information obtained from an EM survey is useful for:

- Initial delineation of spill extent, especially on large sites. For an initial delineation of soil salinity it is usually adequate to determine relative differences in EC values throughout the site, as indicated by the EM values. If required, site-specific correlations between EM and saturated paste EC values can be made;
- Determination of "hot spot" or source locations;
- Indication of variability of salt distribution (low, medium and high reading areas) in soil and groundwater to determine sampling locations; and
- Delineation of spills under adverse conditions.

3.1.3.3 Site Description

The following soil information should be collected where appropriate:

- Complete soil pedon description including kinds of horizons, depth, colour, texture, structure, gley/mottles if present, etc.:
    - Soil classification, and parent material indicate the likelihood that natural salts occur in the soil sample. Although not site specific, published soil survey information for the area can be included;
    - Soil colour, gleying, mottling and drainage class indicate soil hydrologic conditions;
    - Soil texture is important for understanding hydraulic conductivity and infiltration capacity and potential for dispersion;
    - Soil structure is important for understanding hydraulic conductivity and infiltration capacity, and for determining whether salts have altered the soil structure at an old spill.

- Visible salts and carbonates;
- Odour or staining (from other contaminants such as hydrocarbons); and
- Other soil observations: stones, gravel, etc.

Soil profile descriptions should be recorded on soil description forms according to the Canadian System of Soil Classification (Agriculture Canada Expert Committee on Soil Survey, 1987). Borehole logs from groundwater investigations should be recorded according to the Unified Soil Classification System (Holtz and Kovacs, 1981). Include results of field screening where applicable. Table 3.2 lists other types of baseline site information that may be useful.

3.1.3.4 Soil Sampling

Soil sampling, coupled with field and/or laboratory analysis, can provide accurate information on the extent and severity (salt concentration) of the salt contamination if samples are taken, handled, and analyzed correctly. Sampling and analysis can provide information on depth and lateral extent of salt contamination, type, age and source of salt contamination, and concentration of salts in soil. It can also be used to confirm whether other contaminants such as sterilants, hydrocarbons or metals are present in the soil.

A number of decisions need to be made when developing a sampling plan, depending on the nature and complexity of the site and spill, as follows:

Sampling Strategy

- Judgmental: based on prior history (landowner/operator interviews, historical aerial photographs), visual assessment, geophysical survey (used to indicate variability of salt distribution), site characteristics.
- Systematic: consistent grid, pattern, transect.
- Random: simple random selection.

Sample Type

- Single samples are collected at a specific spot at a site (best for delineating variations in salinity; very effective when used in conjunction with geophysical survey).

- Composite samples are derived by combining portions of multiple samples. They are best suited for monitoring previously characterized soils. Generally, only samples that are expected to have the same range of contaminant concentration are composited. Knowledge of the range of concentration may be from prior sampling or geophysical surveying. It is best to use composite samples from the same depth range only. Important information may be lost if the contaminant is diluted in the composite. Composite samples are more expensive to obtain but less expensive to analyze, compared with single samples collected at a specific spot.

Table 3.2 Baseline Information (derived from Dudas 1997)

Surficial Materials and Stratigraphic Units

- Stratigraphic profile
- Type of materials (e.g. clay) or landforms (e.g. lacustrine, eolian, fluvial)
- Texture and hydraulic conductivity
- Thickness of units
- Continuity of units (if known)

Soil and Groundwater Chemistry

- Salinity (most laboratories have a detailed salinity analysis which includes relevant ions such as chloride)
- Sodium adsorption ratio (SAR)
- Electrical conductivity (EC)
- pH
- Carbonate content of soils
- Texture and structure of soils

Bedrock

- Depth of bedrock
- Origin of bedrock: e.g. marine (potentially very saline) or non-marine

Groundwater

- Depth to water table
- Capillary fringe
- Recharge versus discharge
- Water table fluctuations
- Background groundwater chemistry (pH, EC, N, Ca, K, Mg, Na, Cl)
- Groundwater gradient
- Change in water table in response to recharge events
- Location of deep or shallow water tables
- Location of recharge and discharge areas

Landscape

- Percent slope gradient and slope position of salt spill location
- Topography of surrounding land including changes in slope gradient and location of topographical lows (closed depressions and basins)
- Surface drainage, surface moisture and ponding, and locations of coulees or sloughs
- Existing natural occurring saline areas or erosion
- Vegetation type, cover and health

Surface Water Features

- Location of surface water features, including springs, seeps, rivers, sloughs, ponds, dugouts

Nearby Surface or Groundwater Stakeholders

- Locations of water wells, dugouts
- Surface water features used for irrigation, irrigation canals

- Representative control samples must be collected as either single or composite samples from sites adjacent to the contaminated area, unaffected by the contaminant. The use of single or composite sampling should be the same for control and salt affected soils. Again, geophysical surveying can be used to assist in selecting control locations. Controls are used for comparative purposes and should be taken at similar depths and soil horizons to the on-site samples. Control sites should have similar topography, land use, soil type, etc., to the spill area. Controls are essential in salt studies, because relatively high levels of salts are naturally present in soils and groundwater in some areas in Alberta.

- Quality control samples may be required if bias-free or precision data are required. In some cases it may be necessary to differentiate between laboratory and sampling sources of error.

Number of Samples and Locations

- Depending on the complexity of the spill, samples can be selected to represent a range of conditions in the spill area, or to represent a worst-case situation. Fewer samples may be required if a geophysical survey is done. Different remediation methods may be appropriate for different parts of a large spill. In such a situation, the spill area can be stratified into areas of low, medium and high contamination, and sampled within each area. Composite samples can be used if soils, contamination and topography are uniform within the area. If the contaminated area is small and uniform, two sets of samples, one near the edge and one near the centre or in the most contaminated area may be adequate.

- Each sampling location should be assigned a number, which should be recorded clearly on a diagram of the site.

Depth of Sampling

Soils must be sampled to the bottom of the contamination.

- Within the rooting zone (generally considered upper 1 m of soil), undisturbed soils should be sampled by horizon. In disturbed soils without distinguishable horizons, sample by specified increments, for example, 0-15 cm, 15-30 cm, 30-60 cm, 60-100 cm. These increments may change if drastic changes in materials or other conditions are observed within a sampling depth.

- If salts have leached below the rooting zone, sample soils at regular intervals below the rooting zone or where there is a change in soil materials.

- Sampling increments greater than 50 cm are less useful because it is then difficult to pinpoint the vertical extent of contamination.

- Optimum sampling depths are site specific and must be determined by field observations. Field analyses (e.g. field EC meter) can help determine sampling depths.

- Samples taken may be archived and analyzed consecutively by depth until the bottom of the contamination is found.

Cross-contamination

To prevent cross-contamination of soil samples when using solid stem auger sampling:

- Cut off and discard the outside portions of soil samples using a clean, sharp instrument such as a knife. Use only inner portions of sample.

- Start by obtaining the control samples and work from the least contaminated area to the most contaminated area.

- Clean the tools used for sampling between each sample or cut off the inside portion of the sample that was in contact with the tool.

Sample Containers and Labeling

For salinity analysis, soil samples can be collected in heavy duty plastic bags with either Ziplock or twist tie closures. For soils with organic contaminants, pre-cleaned glass jars with Teflon lined lids are required. Most laboratories will supply the necessary sample containers, preservative materials and labels for the appropriate analytical parameters and matrix. Soil with organic contaminants should be stored at 4°C or colder and the laboratory should receive samples within 24 hours of sampling if possible.

When sampling, record the following information: sampling date, time, identification number, sampler's name, sampling site, depth, sample type, sampling equipment, preservative used, time of preservation and any relevant sample site observations. Collect adequate samples for multiple analyses. The amount of sample required will depend on the analyses being carried out; consult the laboratory's manual.

Quality Assurance and Quality Control

Quality Assurance (QA) is a systematic process for guaranteeing that collected data and decisions based on these data are technically sound, statistically valid, and properly documented. Quality Control (QC) procedures are methods used to measure the degree to which quality assurance objectives are met. Appropriate QA/QC measures are based on the data quality requirements of the project, which set the limit for overall uncertainty of results. For more information on QA/QC, see CCME (1993a) and CCME (1993b). General QA and QC measures that are employed for subsurface investigations include:

- Use of proven and appropriate methods by trained field and laboratory personnel;
- Care, cleanliness, maintenance and calibration of field equipment and analytical instruments;
- Documentation of all field and laboratory activities;
- Use of field quality control measures, including field blanks and duplicate sample analyses, to detect contamination during handling, transport, and analytical precision; and
- Coordination with analyzing laboratory for preparation of sampling containers, preservation, packaging, shipping and receipt of samples.

3.1.4 Analysis and Interpretation of Samples

3.1.4.1 Laboratory Analysis

Acceptable methods of soil analysis are documented in Carter (1993) and U.S. EPA (1986). A reputable firm should be selected to conduct the soil laboratory analyses. The most important soil analyses for salt spills include:

- pH, EC and SAR by saturated paste;
- Soluble Na, Ca, Mg, K, SO_4, Cl and HCO_3;
- % saturation; and
- Theoretical gypsum requirement (TGR) (optional).

All of the above parameters are included in the detailed salinity packages offered by many laboratories. The most widely accepted and therefore the preferred extraction for measuring the salinity factors listed above, is a "saturation" extract. It is very important to determine that the laboratory is conducting a "saturation" extract, and not 1:1, 1:2, 1:5 (soil:water) extracts. For comparison to published guidelines, measurement of EC, SAR, and ions must be done using a saturation extract, or data must be corrected to a saturation extract equivalent.

Additional parameters for soil characterization that are sometimes useful include:

- Particle size (experienced field soil personnel can estimate texture by field hand texturing);
- Cation exchange capacity (CEC);
- Carbonate; and
- Gypsum (total gypsum determined by complete dissolution of gypsum and extraction). If the soil has previously been treated with gypsum, it may be important to know how much gypsum is left.

Analyses of co-contaminants may be required if reconnaissance or site information indicates presence of:

- Metals and other inorganics. Presence of higher levels of metals may restrict the remediation options. One element often associated with saline/sodic, high pH conditions is boron.

- Hydrocarbons if reconnaissance and field observations show organic compounds to be a co-contaminant; for example, hydrocarbons in flare pits or mixed phase pipelines.

- Sterilants, herbicides, etc. may be present at some industrial or well sites.

Environmental laboratories can give advice regarding appropriate sampling and analytical techniques for specific contaminants.

3.1.4.2 Field Analysis

Field analysis is useful for initial delineation of the contamination, and to direct sampling locations. Types of field analyses include chloride by Quantab®; electrical conductivity using hand held conductivity bridge; sodium using hand held electrode; pH using hand held electrode. Use a 1:1 soil:distilled water ratio and weigh soil samples for reliable results. Field analysis can be used for most samples, but always in conjunction with laboratory analysis of selected samples. Laboratory results of a saturated paste extract are often about double the field screening results of a 1:1 soil:solution mixture, but this ratio can vary considerably.

3.1.4.3 Interpretation of Analytical Results

To establish whether or not there are adverse impacts it may be necessary to compare control and on-site sample parameters in the application of the regulatory standards. It is also useful to compare the levels to the levels in soil suitable for plant growth (see Appendix A). Table 3.3 summarizes various salinity, soil and groundwater parameters important in the characterization of spills.

Table 3.3 Important Salinity, Soil and Groundwater Parameters for Characterization of Spills (adapted from PITS, 1993)

Salinity Parameters	Comments
pH	Measure of acidity or alkalinity of the soil. Shows the effect of brine on natural soil pH. Used to determine appropriate amendments, potential for nutrient limitations, degree of solubility of many salts, plant growth and species limitations. Optimal values for plant growth are 6.0-7.5. Saline-sodic soils often have pH >8.5.
Electrical conductivity (EC) (dS/m)	Measure of ability of the soil solution to transmit electrical current. Increases with salt content of the soil. Indication of degree of salt contamination. Affects plant growth and species limitations. Very salt sensitive species may be affected at less than 2.0 dS/m.
Soluble SO_4, Cl and HCO_3 (mg/kg or meq/L)	Quantities of major anions. Can use chloride as an indicator of degree of contamination because pristine surface soils in Alberta are generally low in chloride. In most cases SO_4 is an indicator of natural salinity. Higher $Cl:SO_4$ ratios indicate the salts are not naturally occurring. Detrimental effects of chloride to plants are largely from its role in salinity (see EC). Drinking water limit for Cl is 250 mg/l.
Soluble Na, Ca, Mg, K (mg/kg or meq/L)	Quantities of major cations. Na generally an indicator of contamination in naturally non-sodic soils. Ca and Mg are required to determine SAR. K can be an indicator for spills of specific materials such as those related to KCl drilling fluids.
Sodium Adsorption Ratio (SAR)	Indication of the relative amount of Na relative to Ca and Mg in soil solution. As SAR increases (if EC is not high), the structure of medium and fine textured soils degrades. It can be used in the determination of the required amount of calcium amendment. Optimal values are less than 5.0. Higher than 15 is severe. The formula defining SAR is: $\mathrm{SAR} = \dfrac{[\mathrm{Na}]}{\sqrt{\dfrac{[\mathrm{Ca}]+[\mathrm{Mg}]}{2}}}$ where [ ] is in milliequivalents/liter
Percent Saturation (%)	Measure of soil water content at saturation. Used in some cases in the determination of the required calcium amendment. Percent saturation is directly related to texture and organic matter (and thus indirectly to CEC). Also helpful in determining whether a sample is organic or mineral soil when not stated elsewhere.
Theoretical Gypsum Requirement (tonnes/ha usually applies to a 15 cm depth)	As part of detailed salinity package, TGR is calculated by some laboratories from SAR, soluble sodium and percent saturation. Used to estimate the amount of gypsum required to provide enough calcium to replace the exchangeable sodium in soils. The addition of a gypsum amendment is aimed at ameliorating high sodium levels in soil, but does not address soil salinity. There are a number of different methods for assessing the gypsum requirement of a site. Further information on these methods can be obtained from Ashworth and Keyes (1998).

Table 3.3 Important Salinity, Soil and Groundwater Parameters for Characterization of Spills (continued)

Soil Parameters	Comments
Texture	Measure of the amount of sand, silt and clay in soil. Generally measured in the laboratory by the hydrometer method. With experience, one can estimate texture in the field by hand texturing. Fine textured soils are more susceptible to damage from high sodium levels. Used in estimates of hydraulic conductivity, infiltration capacity, cation exchange capacity and amendment requirements. Also useful for estimating workability of soil and best field reclamation methods.
Organic Carbon/ Organic Matter (%)	Field descriptions including colour and soil horizon designations may provide sufficient general information on organic matter contents and types. Organic matter in topsoil generally varies from about 2.5 % to 7 %. Determined in the laboratory by dry combustion or wet combustion (e.g. Walkley-Black) methods. Useful for designing field reclamation methods. May be reported as percent carbon or percent organic matter.
Cation Exchange Capacity (CEC) (cmol(+)/kg	Cation retention capabilities of the soil. Estimated from texture and organic matter content. Used in some cases to determine the required amount of calcium amendment. Clay-rich soils with CEC>50 most difficult to reclaim; sandy soils with CEC <10 to 20 usually easier to reclaim.
Exchangeable Cations (cmol(+)/kg)	Measure of the amounts of various cations on the ion exchange complex. Used in some cases to determine the required amount of calcium amendment.
Exchangeable Sodium Percentage (ESP) (%)	Measure of the percentage of exchangeable sodium on the ion exchange complex: >15 - highly damaged; 10 to 15 – moderately damaged; 5 to 10 - mildly damaged. Indicates the potential for soil colloids to disperse and for poor soil structure to develop. Estimated from SAR by the following equation (Richards 1954): $\mathrm{ESP} = \frac{y}{1+y}(100)$ where $y = (0.01475\ \mathrm{SAR}) - 0.0126$
Bulk Density(mg/m^3)	Measure of density of soil, including natural pore spaces. Bulk Density usually ranges from 1.1-1.5 Mg/m^3 (1.3 Mg/m^3 often assumed for most soils). Sometimes used to determine the required calcium amendment.
Infiltration Rate/Hydraulic Conductivity	Used in determining potential rate movement of water (and dissolved salts) into soil surface and through soil. Also used to indicate extent of damage to soil physical characteristics caused by salt or to assess the effectiveness of reclamation measures imposed. Information on measurement can be found in soil physics or irrigation/drainage engineering books (e.g. Hillel 1980a).
Calcium Carbonate Equivalent	Shows the presence of calcium reserves in soil as carbonate, which may be mobilized by acidification of the soil. Available analysis at commercial laboratories.

Table 3.3 Important Salinity, Soil and Groundwater Parameters for Characterization of Spills (continued)

Groundwater Parameters	Comments
Gypsum ($CaSO_4 \cdot 2H_2O$)	Measure of the amount of gypsum in the soil. Useful measurement for old spills where calcium amendments have been used in the past. Used in some cases to determine the required amount of calcium amendment for spills that have previously been treated.
Depth to Water Table	Depth of the water table is measured in wells that have a screened interval that includes the water table. Indicates shallow hydraulic conditions present on the site.
Vertical Hydraulic Gradients	Determines whether the area is a recharge or discharge area, or if the groundwater flow is horizontal. A nest of at least two piezometers is required.
Horizontal Hydraulic Gradients	Represents the direction and magnitude of the slope of the water table; or, for confined units, the slope direction and magnitude of the piezometric surface. Allows an estimate of the velocity to be calculated by the equation: $V=Ki/n$, where: K = hydraulic conductivity, i = hydraulic gradient; and n = porosity. The result gives an estimate of the maximum migration rate of ions (e.g. chloride) in water.
Hydraulic Conductivity	Determined from single well slug or bail tests, or from multiple well pumping tests. Reflects the ability of a soil to transmit water.

3.1.5 Groundwater Sampling and Analysis

When salts have entered groundwater, or are expected to do so, a groundwater assessment should be conducted. The objectives of a groundwater assessment are to:

- determine the nature and extent (horizontal and vertical) of any impacts on groundwater quality;
- establish the groundwater circulation regime, together with flow directions and velocities, particularly with respect to possible exposure pathways, and
- identify the nature of potential changes in conditions over time.

To verify the expected changes in groundwater conditions over time (or lack thereof), a groundwater monitoring program may be considered an appropriate component of a site assessment. This is especially the case where immediate management of impacts is not required, but where the potential exists for future impacts to be of concern.

3.1.5.1 Installation of Observation Wells

Observation Well Location

Observation wells are constructed as standpipe piezometers and should be placed in locations surrounding the suspected sources of groundwater contamination. Although most wells will be constructed downgradient from the suspected source, upgradient and lateral locations are required for both background assessment and evaluation of geologically complex settings.

Some or all of the observation wells may be installed in subsoil sampling boreholes. However, it should be recognized that these may not always be logical locations for well placements.

Design and Installation of Observation Wells

Groundwater observation wells should be constructed with flushjoint, threaded pipe (typically Schedule 40 PVC) casings which have a minimum inside diameter of 50 mm. These are installed in a boring whose diameter is at least 100 mm greater than the diameter of the casing.

Observation wells should be constructed as filter-packed wells so that particles of natural soil cannot enter. A uniform sandpack is recommended. The well screen should be factory perforated with a slot size adequate to prevent entry of filter material. Filter packs should extend approximately 0.5 m above the perforated screen interval to allow for compaction of the filter material. All standpipes shall have a bottom cap or plug.

Proper well construction is essential to ensure the observation well itself does not become a route for contaminant migration. Wells should be constructed where possible to provide depth-discrete measurements for individual "flow" zones. When hydrocarbon contamination is suspected in addition to salts, slotted screen intervals must be located to coincide with the groundwater surface in order to measure the accumulated thickness of any phase-separated hydrocarbon product (free product). Installation of a continuously slotted screen that cuts across and links several flow zones should be avoided to minimize the risk of cross zone contamination. This is of particular concern in subsoil units where free product is evident, and in areas where the location of the stabilized groundwater surface is unknown or where large seasonal fluctuations may occur. In these areas, a "nest" of several piezometers (installed in separate adjacent boreholes) with slotted screen intervals at varying depths is recommended to enable independent observation of several horizons or flow zones.

Groundwater observation wells should be sealed from the top of the filter pack to the ground surface. The backfill material installed above the filter pack should be a low permeability material with known chemical properties (e.g.. bentonite). The use of drill cuttings as backfill will not ensure an adequate seal. The uppermost metre of the well annulus should be backfilled with a concrete grout. The grout should extend above the ground surface and be finished to slope away from the well axis to prevent downhole infiltration of surface water. Well heads should be fitted with a water tight cap and enclosed in a structure that secures the well against accidental damage, unauthorized access, and vandalism.

In some instances it may be necessary to target more than one permeable strata in order to assess the possibility of vertical contaminant migration. In this case a nest of standpipe piezometers would have to be constructed. The individual piezometers must be carefully constructed to isolate the individual strata and prevent cross-contamination.

Subsoil stratigraphy and lithology should be logged and subsoil units classified according to the Unified Soil Classification system prior to the well construction. A sketch of each well should be constructed with apparent groundwater elevations on the borehole/well log. All wells should be surveyed relative to a suitable bench mark for the measurement and evaluation of groundwater elevations.

3.1.5.2 Groundwater Monitoring and Chemical Sampling

It is essential that water levels stabilize prior to use of the elevation data to assess groundwater flow. Monitoring of water levels and free product thickness should be conducted at least twice and on separate site visits. The actual number of monitoring events will depend on well stabilization rates.

All observation wells should be monitored for water levels and, when hydrocarbons are present, the presence of any phase-separated (free) hydrocarbon product floating on the water surface. If free product is present its thickness should first be measured using an interface probe. Where possible, the free product should be removed, its volume recorded, and additional monitoring conducted to determine recovery rates. Samples of free product should be collected for laboratory characterization of the contaminant.

Prior to sampling of groundwater for dissolved constituent analyses, the well must be purged to remove all stagnant water retained in the standpipe. Pumping or bailing of at least four times the calculated standpipe water volume or to dryness is recommended. The groundwater sample may then be collected using a bailer or other suitable device. Collected samples once transferred should have no visible headspace or evidence of any free product. Samples should be stored in ice filled coolers while on site, and transported immediately after sampling to the analyzing laboratory, along with chain of custody documentation.

Groundwater samples can be collected using dedicated sampling devices or by using portable equipment. Dedicated sampling devices for each well installation are recommended since:

- the risk of cross-contamination is reduced, and
- analytical results tend to be more consistent.

The chemical composition of groundwater is often indicative of the source of the contaminants. A groundwater analysis program should include, but not be limited to, calcium, magnesium, sodium, potassium, chloride, sulphate, nitrate, hardness, alkalinity, pH, electrical conductivity and total dissolved solids. Groundwater composition can be highly variable due to the physical and chemical properties of the material through which the groundwater flows.

3.1.6 Site Assessment Reporting

Depending on the purpose of a given site assessment, the report may include the following:

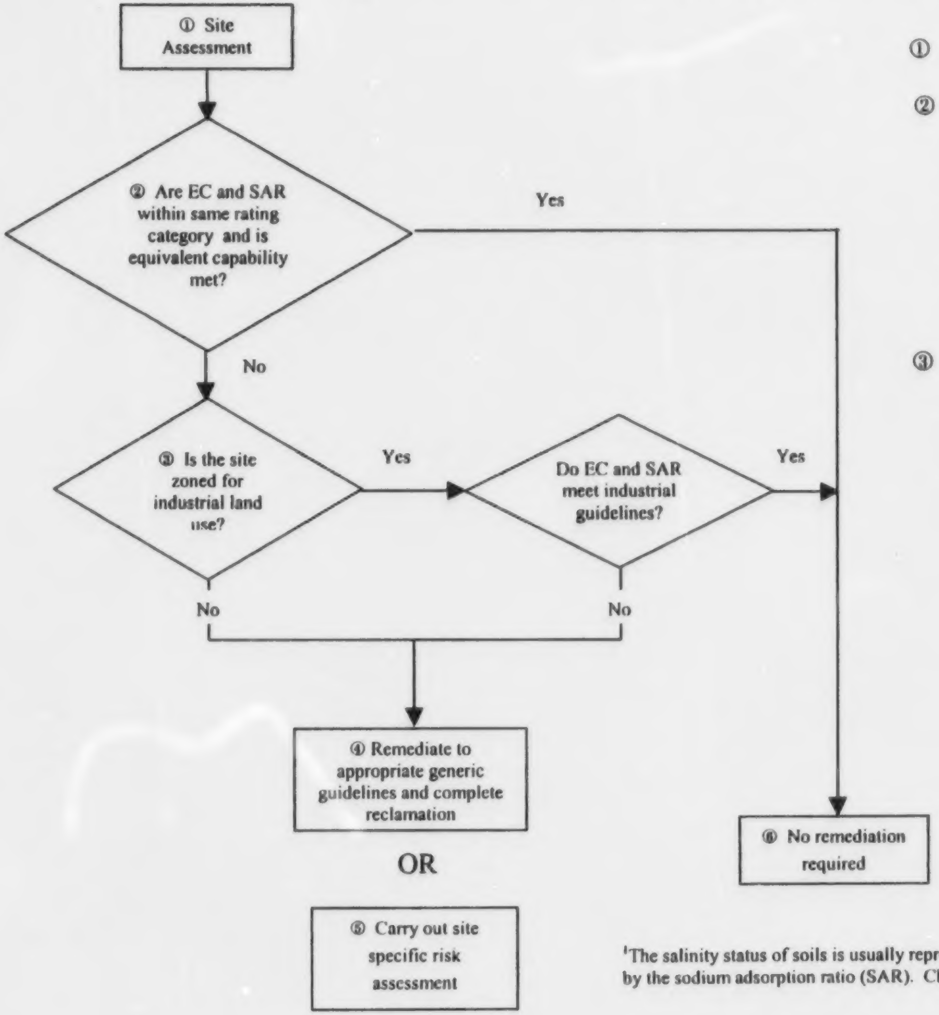
- Introduction, site location, purpose of assessment, scope of work;
- Description of site, site history, stakeholder input, methods used;
- Site sketch or diagram;
- Presentation of data;
- Interpretation of data;
- Recommendations and/or conclusions; and
- Maps and other supportive materials.

3.2 Remediation Objectives

The findings of the site assessment must be compared to the generic guidelines in Table 2.3 to determine if regulatory requirements have been met. Under certain circumstances, site-specific risk-based objectives may be developed as an alternative to generic guidelines. Further details on risk assessment are provided in Section 2.4.2 and Section 4.0.

Figure 3.3 illustrates procedures associated with determination of appropriate soil remediation objectives.

Figure 3.3 Determination of Appropriate Soil Remediation Objectives Flow Chart


① Site Assessment
② Are EC and SAR within same rating category and is equivalent capability met?
Yes
No
③ Is the site zoned for industrial land use?
Yes
Do EC and SAR meet industrial guidelines?
Yes
No
No
④ Remediate to appropriate generic guidelines and complete reclamation
OR
⑤ Carry out site specific risk assessment
⑥ No remediation required

① See Section 3.1.

② Compare the results of laboratory analyses of the contaminated soil with analyses (EC[1] and SAR[1]) of the control background soil. Determine if the levels of salt and sodium are in the same rating category or better as defined in Table 2.2 or less than background if in the "unsuitable" category. In some areas of Alberta, background levels of salt and/or sodium may be high.

③ If the site is in industrial use and is zoned industrial, then the CCME Industrial/Commercial guidelines may be used (Table 2.4). In using these guidelines, some liability remains with the proponent with respect to future change of the site to a more sensitive land use.

④ See Section 2.4.1.

⑤ See Sections 2..4.2.

⑥ Carry out reclamation as required.

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[1] The salinity status of soils is usually represented by electrical conductivity (EC; units of deci-Siemens/metre), and the sodium status by the sodium adsorption ratio (SAR). Chloride levels in soil are usually represented as concentration in mg/kg.

3.3 Remediation Options

If the site assessment determines that the site fails to meet the guidelines, remediation to generic or site-specific risk-based guidelines is necessary. Figure 3.4 illustrates the remediation process.

The goal of remediation is to achieve Alberta's Environmental Protection and Enhancement Act requirements to prevent or mitigate adverse effects caused by the release of substances. On sites of existing spills, adequate identification and assessment of contaminated areas facilitates remediation planning and results in more efficient and cost effective remediation.

In remediation planning, whether remediating to generic guidelines or risk based levels, any increase in the likelihood of salt movement to receptors caused by remediation operations should be minimized and possible adverse effects should be taken into account. The risk of adverse effects on potential receptors depends on the severity and extent of the spill in combination with site characteristics. **If the risk assessment approach is chosen, the risk must be characterized in a formal report and submitted to Alberta Environment (Regional Office, Environmental Service).** Remediation should not be delayed where there is a risk of adverse effects on receptors.

In general in-situ remediation of salt contaminated soil involves:

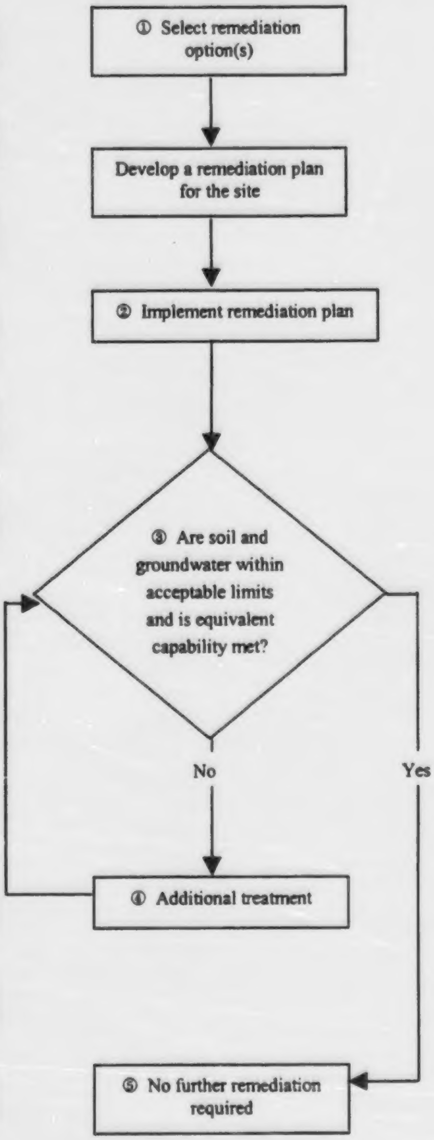
1) Replacement of sodium on the soil particles with calcium; and

2) Subsequent removal of salts including sodium, in the soil solution by leaching with natural precipitation or irrigation. This step may involve collection and proper disposal of leachate.

In-situ remediation, on-site soil washing or other treatments must not result in additional adverse effects on or off the site through transfer of contaminants to other media (e.g. groundwater). Therefore proper collection and disposal of leachate must be part of the remediation where there is potential for causing further adverse effects.

Remediation options chosen must be appropriate for site and spill characteristics. See Table 3.4 for information on suitable conditions for these options and advantages and disadvantages.

Figure 3.4 Remediation Flow Chart


① Select remediation option(s)
Develop a remediation plan for the site
② Implement remediation plan
③ Are soil and groundwater within acceptable limits and is equivalent capability met?
No
Yes
④ Additional treatment
⑤ No further remediation required

① Site conditions must be appropriate for the remediation option chosen. Depending on site and spill characteristics, more than one option may be required.

② The spill site should be monitored during remediation to ensure the remediation objectives will be met and there is no movement of salts off-site and to potential receptors. This may include geophysical surveys, and/or sampling and analysis of soils and surface/groundwater where necessary.

③ Acceptable limits are the generic guidelines or the site-specific guidelines developed (and approved by Alberta Environment) in the risk assessment (Section 2.4).

Assessment and verification of remediation should be done by sampling and analysis of soils, and surface/groundwater where necessary.

Where a risk reduction/risk management program has been undertaken on-going monitoring is required as specified in the risk reduction/risk management plan to ensure the assumptions in the plan were valid, and the plan objectives are being met.

④ Remediation of a salt contaminated site can be a slow process depending on site and soil characteristics, severity and age of the spill, and amount of precipitation/evaporation or irrigation water available for leaching of salts from the root zone. Multiple treatments over a number of years may be required to reach the remediation objectives.

⑤ EPEA requirements for no adverse effects and return to equivalent capability must be met in order to consider closure of remediation on a site.

Table 3.4 Soil Remediation Options

If stated conditions are not met, another option(s) should be considered. If not sure if conditions are met, undertake further investigation, or choose another option(s). For all options, there must be no adverse effects on potential receptors during or after the remediation. Also, remediation should not be delayed where adverse effects on receptors are occurring. Use of more than one of these options may be required.

Note: Forested and wetland sites present additional challenges not found in agricultural areas. Site-specific features such as nutrient regime, hydrology, and sensitivity to disturbance must be taken into account when developing remediation strategies.

Options	Considerations for Appropriate Use
1. In-situ remediation with: • Addition of liquid/solid calcium amendment to replace sodium in the soil; • Reliance upon subsequent precipitation to leach salts down through, and out of the surface soil.	1. Little or no risk of contaminant movement from spill area and potential adverse effects. 2. No adverse impact on groundwater. 3. Site, soil and climate conditions adequate to allow for net downward movement of water. Precipitation must exceed evapotranspiration sufficiently to allow net moisture flux into soil. 4. Sufficient soil drainage for salts to be leached out of the root zone. Consideration of hydraulic conditions (as determined by soil permeability, groundwater depth, topographic location, etc) is required. If hydraulic conditions are not adequate, another option will be necessary. Salts must be leached to a depth below the root zone, and to a depth at which capillary movement of soil water will not result in salts moving up into the root zone. 5. Replacement of sodium by the calcium may require several applications of calcium amendment depending on spill and site characteristics. Time will be required for salts to leach to a sufficient depth. 6. Appropriate conditions for this option are normally only met on **non-sensitive** sites (absence of shallow groundwater, high permeability soil, etc.) with relatively **minor** spills (shallow depth, and small volume of non-severely contaminated soil and salts). 7. Likely most successful in Black and Gray Soil Zones due to climatic conditions.
2. In-situ remediation with: • Addition of liquid/solid calcium amendment to replace sodium; • Subsequent flushing with irrigation water to accelerate leaching of salts out of the soil profile.	1. Leaching may need to be enhanced by the addition of supplemental water (irrigation) where salt levels are slightly higher, spills are in finer textured soil (see item 7 below), or in drier areas of the province. 2. See items 1-4 for option 1 above. 3. Collection of leachate is necessary to avoid adverse effects in many cases (see option 3 below). Proponents who use this option without collection of leachate must be prepared to demonstrate there is no risk of adverse effects. 4. Subsequent to replacement of sodium with calcium, good quality irrigation water low in salts should be used. 5. An appropriate rate of application and volume of irrigation water should be used. 6. Erosion or offsite movement of salt via surface runoff must be avoided. 7. In fine textured soil that has been dispersed and has low permeability, leaching will be more difficult; extra consideration should be made to rate of water application and using physical methods to increase soil infiltration and permeability. 8. Likely necessary in Dark Brown and Brown Soil Zones due to climatic constraints.

Table 3.4 Soil Remediation Options (Continued)

3. In-situ remediation with: • Addition of liquid/solid calcium amendment to replace sodium; • Flushing with irrigation to accelerate leaching of salts out of the soil profile (may require erosion control); • Collection of leachate and appropriate disposal.	1. For larger or more severe spills, or wherever there is a risk of salts moving into groundwater or other receptors, artificial drainage should be put in place to collect the leachate. 2. See items 4-7 in option 2 above. 3. The leachate must be collected and disposed of at an appropriate disposal site. See Energy and Utilities Board Guide 58 (EUB 1996b) for the responsibilities of the oilfield waste generator.
4. Excavation of salt contaminated soil and on-site soil washing with collection of leachate and appropriate disposal.	1. Contaminated soil must be stored and washed in a manner to prevent further movement of salts into soil or water. This may involve construction of an impermeable treatment pad and leachate collection system. 2. The soil wash water must be collected and disposed of at an appropriate disposal site. 3. Soil washing is less effective on fine textured soils. 4. May require re-establishing soil structure through the use of forages and organic amendments. 5.
5. Excavation of salt contaminated soil and disposal at an approved disposal facility.	1. See Energy and Utilities Board Guide 58 (EUB 1996b) for the responsibilities of the oilfield waste generator.
6. Additional amendments.	1. Additional amendments of organic matter are beneficial, particularly where leaching over time has resulted in soils with an acceptable low pH and EC, but a high SAR. Organic amendments can assist improvement of poor soil structure caused by high sodium content in conjunction with a low ionic concentration of the soil solution. 2. Other amendments may be beneficial to adjust soil pH or nutrient deficiencies.
7. Other Remediation technologies.	1. Other options not listed may be considered acceptable by Alberta Environment with proper investigation and documentation. 2. Natural recovery may be an option in specific cases in which the salt effects are minor and natural processes are expected to remediate the site in a reasonable amount of time or in cases in which additional work could further deteriorate the environment. For example, on a spill site in native range in Southern Alberta with sandy soils and re-established vegetation but with EC and/or SAR levels above generic guidelines. Further work may lead to wind erosion and further difficulties in establishing vegetation.

Some remediation options (e.g. excavation of all contaminated soil and disposal at an appropriate disposal site) usually have low risk of adverse effects on potential receptors provided proper techniques are used. In options involving treatment with a calcium amendment and reliance on precipitation for leaching of minor salts at non-sensitive sites (e.g. small extent/volume of non-severely contaminated soil to a shallow depth), the risk of causing additional adverse effects is relatively low. However even in these cases, consideration should be given to the potential movement of the salts and adverse effects on receptors. Such factors as total mass of salts present, volume of contaminated soil, depth to groundwater, permeability of subsoil, potential to cause saline seep, and other potential receptors nearby should be considered. As salt contaminated soil increases in volume (extent and depth) and severity, and as the site characteristics become more sensitive (e.g. shallow groundwater, water well nearby, contamination at top of slope, etc.), greater care must be taken to mitigate potential adverse effects to receptors before, during and after remediation.

3.3.1 Initial Salt Spill Response

For detailed initial spill response procedures, please refer to comprehensive documents that are available such as those from Petroleum Institute Training Service (1993, 1997).

Certain actions undertaken during the initial spill response can facilitate subsequent remediation and reclamation efforts. Topsoil should be conserved where possible, even if it has been contaminated. It may be necessary to store contaminated topsoil on an impermeable pad or liner until remediation. High sodium soil that is flushed with fresh water will disperse if electrical conductivity falls below a critical level, making future reclamation more difficult. **Sites with high sodium levels in the soil should not be flushed with fresh water when electrical conductivity is approaching or below the critical level for dispersal**. Addition of a calcium amendment with flushing water will displace the sodium from the soil and stabilize the soil structure. Leaching of salts can then occur with less risk of dispersion. Adding calcium, in particular soluble source such as calcium chloride or calcium nitrate, while electrical conductivity is high will result in some loss of added calcium in drainage water. However if initial flushing is done with fresh water, extreme care must be taken to ensure electrical conductivity does not drop below the level where dispersion will occur. (See Appendix A4.3 for more information.)

Immediately after spill containment and recovery operations have been completed, the first spill treatment should be applied. A ready source of equipment and amendments should be available so that the first treatment can be applied while the site is still wet. An initial application of a calcium amendment in a water-soluble form should be undertaken, followed by application of gypsum. Calcium nitrate fertilizer is a good source of soluble calcium. Liquid calcium amendments containing calcium nitrate are available commercially. Note that **nitrate contamination of surface and groundwater is a concern, especially when calcium nitrate is applied to an irrigated site or to a site with sandy soils or a high water table**. The maximum amount of calcium nitrate that can be safely applied is a function of the characteristics of the specific site (soil texture, hydraulic conductivity, groundwater depth, etc.).

Ensure proper storage and disposal of saline waste and water. Documents such as the Energy and Utilities Board Guide G-58 (1996b) and Guide 50 (1996a) define proper disposal of oil field wastes. Brines and saline water should be disposed of in an appropriate deep well injection facility. Well classifications for injection wells are included in the Energy and Utilities Board Guide G-51 (1994). Storage requirements for the upstream petroleum industry are found in Energy and Utilities Board Guide G-55 (1995).

3.3.2 In-Situ Remediation

In-situ remediation with calcium amendments is a remediation option if sodium can be displaced from the soil and salts can be permanently leached below the root zone. **This method requires collection and proper disposal of leachate at sites where there is risk of significant movement of salts to groundwater or other receptors, or where hydraulic conditions prevent the salts from being leached out of the root zone.** In order to properly plan and carry out in-situ remediation of salt contaminated soil, an individual should understand the concepts of EC, SAR, soil dispersion and leaching, as well as the relationships between these parameters. Many of the concepts important to in-situ remediation are also applicable to ex-situ soil washing.

In-situ remediation of saline-sodic soils involves:

1) Replacement of exchangeable sodium with calcium while maintaining sufficient EC in the soil solution to prevent swelling and dispersion;

2) Subsequent removal of salts (including sodium) in the soil solution by leaching with natural precipitation or irrigation. This step may involve collection and proper disposal of leachate.

These steps must be carried out in the above order to avoid dispersion and further deterioration of soil conditions, as well as to facilitate remediation.

3.3.2.1 Required Site Conditions for In-situ Remediation

Precipitation, if sufficient, or irrigation can be utilized to (1) dissolve (if in dry form) and move the calcium amendment into the affected soil layers for replacement of the sodium and (2) leach the salts down through the root zone. In-situ remediation requires that hydraulic conditions at a site must allow for a **net downward movement of water and salts** in order to be successful. These conditions include sufficient precipitation, and soil and groundwater conditions that allow sufficient internal soil drainage. Otherwise, application of irrigation water and/or improvement of drainage will be necessary, or another remediation option must be selected. Salts must be leached below the root zone to a depth at which capillary movement of soil water will not result in salts moving up into the root zone or to the depth of installed drains.

Each spill site should be assessed individually to ensure that the treatment and calcium amendments chosen are the most effective and will not result in the movement of salts that will cause further environmental impacts (e.g. on groundwater). Flushing of soluble salts to the groundwater flow system (i.e. without collection of leachate) is only acceptable when a site assessment demonstrates that there is no risk of impacting groundwater or down-gradient receptors. Flushing of small volume spills or spills in areas where there are no receptors, or relying on natural leaching and attenuation of soluble salts may be acceptable to Alberta Environment if it can be demonstrated that there are no additional adverse effects caused by these treatments.

In addition to severity and distribution of the salt contamination, site characteristics must be considered. Several factors may limit the effectiveness of in-situ remediation, whether relying on precipitation or irrigation to move the calcium amendment into the affected soil and to leach the salts out of the root zone. In planning in-situ remediation and leaching of salts consider the following:

- Characteristics of the soil (e.g. permeability and pattern of subsurface water movement, presence of Solonetzic soil), the contaminant, and the site (e.g. topography, proximity to water bodies/wells/dugouts, depth to groundwater, potential of saline seeps forming) will dictate the appropriate irrigation, drainage, and leachate collection methods.

- Dispersed soil may retard soil internal drainage and leaching.

- A high water table may not allow sufficient downward movement of the calcium amendment or salts; installation of drains may be necessary if groundwater is within 2-3 m of the surface.

- Impermeable layers may retard downward drainage of the calcium amendment and salts through the root zone and could cause a perched water table.

3.3.2.2 Replacement of Sodium in the Soil with Calcium

Replacement of exchangeable sodium ions can be accomplished by increasing the calcium concentration in the soil solution by the addition of a calcium amendment. The ions on the soil particles are in a dynamic equilibrium with the soil solution. Therefore, a high concentration of calcium in the soil solution will result in calcium replacing sodium on the clay surfaces, and in the process, lowering the SAR. The Gapon equation:

$$\mathrm{ESR} - 0.015\,(\mathrm{SAR}),$$

where ESR is exchangeable sodium ratio, can be used to monitor conditions that influence the exchange of calcium by sodium.

After a recent spill, the ionic concentration (EC) of the soil solution should not be allowed to fall below the level at which dispersion occurs until sufficient calcium has been applied to replace most of the sodium on the cation exchange complex and lower the SAR to acceptable levels. The critical level will be site specific, but may be estimated by means of a laboratory treatability study. On-going monitoring of EC and SAR indicate the progress of the remediation. Maintenance of the high EC prevents dispersion and promotes greater infiltration rates and hydraulic conductivity of the soil. This maximizes the movement of water into and through the soil, which is necessary for the movement of calcium amendments into the soil and for the leaching of salts from the soil solution. As the SAR of the soil decreases, the EC required to prevent dispersion also decreases. Once the SAR has been lowered, salts can be leached out of the soil solution (lowering the EC) without promoting dispersion. Preventing dispersion is an important consideration in medium and fine textured soils.

The time and effort that is required for in-situ salt remediation will vary greatly depending on the site and spill conditions. Remediation procedures vary with the characteristics of the spill (volume, severity, age, extent, etc.) and the site (soil type, topography, groundwater characteristics, etc.). It may take several years and several treatments to return an area to productive use. Factors that will increase the time and effort required include:

- Impermeable soils (including dispersed soil);
- Fine textured soils;
- Shallow groundwater table;

- High EC/SAR levels;
- Low precipitation;
- Pathways which promote movement to receptors (such as surface water and groundwater); and
- Remediation effort (e.g. number of amendment applications).

3.3.2.3 Calcium Amendments

Calcium amendments can be added to the soil in dry or liquid form. Liquid calcium amendments are faster acting, and have a deeper initial penetration depth. Commercial formulations of liquid calcium amendments are available in concentrated form. Liquid amendments can also be made by dissolving calcium sources in water. The most commonly used dry amendments are gypsum ($CaSO_4 \cdot 2H_2O$) and calcium nitrate ($Ca(NO_3)_2$), although calcium chloride ($CaCl_2$) may be used if adequate drainage control is in place. Use of calcium amendments may require subsequent irrigation and leachate collection. Table 3.5 summarizes some of the attributes of these calcium amendments.

Gypsum, which is moderately soluble, readily available and inexpensive, is the most commonly applied calcium amendment. In addition to supplying calcium for the replacement of exchangeable sodium, the sustained release of electrolyte from gypsum contributes to the maintenance of the hydraulic conductivity and assists remediation of saline-sodic soil (Sumner, 1993).

To effectively replace sodium on the soil cation exchange complex, the calcium must be able to dissolve, and the hydraulic conditions of the soil must allow for infiltration of water with high calcium concentration down into, and through, the contaminated soil pores. The amendments may be applied at different rates on different areas, depending on the variation in EC and SAR levels. Uniform application of amendment over an area of given salt severity will help optimize its effectiveness. Generally, a more permeable soil is de-salinized more uniformly and rapidly than a less permeable one.

Dry amendments must be thoroughly mixed into the soil to maximize their effectiveness and minimize loss from runoff. Dry amendments depend upon precipitation or irrigation to dissolve the amendment and carry the calcium into the soil solution. Gypsum is the more commonly used amendment on Alberta soils, and is a slow release source of calcium ions to the soil. Less soluble forms of calcium (e.g. limestone) are not as commonly used as they are only effectively dissolved under acidic soil conditions ($pH<6$), and most Alberta soils have nearly neutral pH.

Table 3.5 Most Commonly Used Calcium Amendments

Amendment	Formula	Available as	Characteristics
Gypsum (calcium sulfate)	$CaSO_4.2H_2O$	Bulk or sack	• Slow release over a longer time than calcium nitrate; poorer solubility- about 1 vertical ft water required to dissolve about 50 pounds of gypsum/100 sq. ft of very saline soil. Solubility increases with salt concentration - twice as soluble at EC of 15 dS/m vs. EC of 3.5 dS/m. Final top dressing will assist in preventing dispersion and crusting at surface. • Broadcast on surface and incorporate. Must have sufficient precipitation to dissolve and move down through the soil. Can also be applied as a slurry. • Maximum application of 20 tonnes/ha is the upper limit often given by laboratories. • By-product gypsum (e.g. phosphogypsum) is more soluble than mined gypsum (Sumner, 1993), however presence of naturally occurring radionuclides in phosphogypsum may limit the quantity that can be applied.
Calcium Nitrate	$Ca(NO_3)_2$	Bulk, sack or liquid	• In dry pellet form, more soluble, deeper and faster acting than gypsum; penetrates soil quickly with water. • **Excess nitrates in water can be a hazard to human and animal health (see Section 2.4).** Therefore limit the amount applied or do not use where there is potential for the nitrate to move into surface or groundwater. • Apply at a rate at which nitrate levels leaching into the soil or groundwater will not adversely affect soil and water quality. • Nitrate is a plant nutrient. • A significant amount of nitrate may be converted to other forms of nitrogen by denitrification under anaerobic conditions. • Broadcast on surface and incorporate or apply as liquid or slurry. Application rate must not exceed infiltration rate unless measures have been taken to avoid surface runoff and the resultant movement of salt, and erosion. • Commercially available as a dissolved, concentrated liquid product that moves into soil and replaces sodium quickly; relatively expensive. • Often co-applied with gypsum. Calcium nitrate is about 24.3 % calcium and gypsum about 23.3 % calcium, so about .95 kg of calcium nitrate can displace the same amount of sodium as 1 kg of gypsum, if the entire amount of each is dissolved.

On the first application of a calcium amendment, it is often beneficial to apply both faster acting calcium nitrate and slower release gypsum together. The theoretical gypsum requirement (TGR) can be used to determine the amount of calcium amendment theoretically required to replace the sodium. TGR can be determined from soil samples by a reputable soil laboratory. Once the amount of calcium nitrate to be added is decided upon, the amount of gypsum that has an equivalent amount of calcium to that in the calcium nitrate can be calculated (see Table 3.5, Calcium Nitrate). This equivalent amount of gypsum is subtracted from the TGR to give the amount of gypsum to be added with the calcium nitrate.

The amount of calcium nitrate applied is often limited by concerns about nitrate contamination of groundwater. The amount that should be applied will depend on the potential for movement of the nitrates into groundwater. Sites of greater concern are those with high permeability soils (e.g. sandy), shallow groundwater, high rainfall or applied irrigation water.

The most straightforward method to monitor the remediation progress is to sample the soil being treated and analyze it for SAR and EC (included in most laboratories' standard salinity package). After an initial application, monitoring may indicate that further amendments would be beneficial. Subsequent applications may consist of calcium nitrate and gypsum together or gypsum alone. Monitoring of the spill should continue until site recovery is complete.

3.3.2.4 Other Amendments

There is considerable evidence that organic matter tends to counteract the unfavourable effects of exchangeable sodium (Richards, 1954). Over time, organic matter improves soil structure, bulk density, nutrient supplying capacity, permeability and aeration. Well-decomposed organic matter (e.g. old manure) is more quickly beneficial to soil structure than fresh organic matter.

Organic amendments must be thoroughly worked into the topsoil upon application. Fertilizer containing nitrogen should be added with significant amounts of organic matter, because nitrogen is used up as the organic matter decomposes. Use only well-decomposed or composted manure to help prevent an increase in weeds. Addition of significant amounts of certain organic amendments (such as chicken or some feedlot manures) can increase soil salinity (usually over several applications). Testing manure and compost for salinity is recommended (de Jong, 1979). Refer to "Organic Materials as Soil Amendments in Reclamation" (Land Resources Network Ltd., 1993) for more information.

Use of synthetic polymers (e.g. polyacrylamides) to stabilize aggregation has also proved useful in improving the physical properties of high sodium soil (Sumner, 1993).

3.3.2.5 Salt Leaching, Drainage, Containment and Disposal

Water draining through the soil will move salts down through the soil. However, the volume of water must be sufficient to carry salts through the root zone to the drain tile or to below the depth where upward capillary movement might cause re-salinization of the surface soil. In order to accomplish this, the volume of water must be more than that which is evaporated, taken up by vegetation, and stored in the soil. In moist areas natural precipitation may provide enough water. In dry areas, irrigation water will need to be applied for effective leaching.

The leaching requirement has been used to represent the fraction of precipitation or irrigation water that must be leached out of the bottom of the root zone in order to reclaim saline soil to a specific level of salinity. The leaching fraction of the irrigation water is defined by the equation:

$$LF = \frac{\text{volume of water leached below root zone.}}{\text{volume of water applied}}$$

The total volume of water added must account for the required leaching fraction.

Less water leaches through the bottom of the root zone than is applied because some water is stored in the soil and some is lost through plant use and evaporation. As the leaching fraction is increased, the amount of salts leached per depth of soil increases (Bohn et al., 1985). Several studies have found that one depth of leaching water (1 m^3 of water = 1 m of water per m^2 of soil surface) will generally decrease the salt concentration of an equivalent depth of soil by about 70 - 80 % (e.g. Bohn et al., 1985; Hoffman, 1980). As the volume of drainage water approaches the volume of water applied, the salt concentration of the drainage water approaches that of the added water. However, enough water must be applied to achieve complete leaching. If insufficient water is applied, salinity levels may actually increase as shown in the example below:

Assume: $LF = 0.35$
$EC_{(\text{leaching water})} = 1.5$ dS/m

$EC_{(\text{reclaimed soil})} = 1.50 / 0.35 = 4.3$ dS/m

Leaching with Precipitation

Precipitation must be sufficient to dissolve the calcium amendments (if in dry form), move the calcium ions through the soil and subsequently leach the salts out of the soil. Where there is adequate rainfall for leaching, a number of measures can be instituted to speed up the leaching process. Many parts of Alberta do not receive enough precipitation to carry salts through the soil profile. The subhumid climatic regions (Black and Gray Soil Zones) may receive enough moisture in some years to allow leaching by natural precipitation. In general terms, anything that helps water move into and through the soil profile will assist the leaching process. Snow fencing, straw bales and standing stubble all help trap snow for additional moisture. Tillage and paratilling can improve soil permeability by breaking up surface crusting.

Leaching with Irrigation

The addition of water to a site may be necessary if precipitation does not provide enough water. Irrigating the soil can be carried out to ensure adequate leaching of soluble salts down through the soil away from the root zone. Adding water to the site increases the risk of movement of salts to the groundwater or other receptors. This could lead to environmental impacts such as degradation of groundwater quality, or formation of a saline seep downslope. Thus, leachate may require collection and proper disposal, depending on the potential for environmental impacts.

Application of Irrigation Water

Leaching water is commonly applied by gravity (continuous or intermittent ponding) or sprinkler application. Ponding water on the surface is accomplished by means of dikes or berms. The rate of application must not exceed the rate of surface or soil profile infiltration, unless steps are taken to prevent surface runoff and/or erosion. Intermittent application of leaching water and allowing the soil to drain between applications has been found to be more efficient in remediation of natural soil salinity with respect to the amount of water used, than continuous ponding (Alberta Agriculture, 1980). Leaching will be most uniform when the water is applied uniformly.

Volume of Irrigation Water Applied

As discussed above, when irrigation is practiced in arid regions (particularly if the irrigation water has appreciable salt concentration), the processes of evaporation and transpiration tend to concentrate salts in the root zone. To prevent salt residues from accumulating during repeated irrigation-evapotranspiration cycles, sufficient water must be applied such that a significant fraction of the applied water flows through and past the root zone to leach away the excess salts. Application of too little water will fail to leach salts adequately. Application of too much water is wasteful and may cause erosion, removal of nutrients, waterlogging and poor aeration of the soil, or rise in a shallow groundwater table, increasing the capillary rise of salts.

Irrigation Water Quality

Poor quality irrigation water may add sodium salts to the soil, and should not be used. Good quality (low EC) irrigation water is particularly important near the end of a remediation project, when EC and SAR levels are nearing objectives. Guidelines for irrigation water quality are listed in Table 3.6.

Table 3.6 Irrigation Water Quality Guidelines (Alberta Agriculture 1983)

Irrigation Water Parameter	Safe (all conditions)	Possibly Safe	Hazardous
EC dS/m	<1	1 - 2.5	>2.5
SAR	<4	4 - 9	>9

Artificial Drainage

Installation of drains will be required where the hydraulic conditions on site do not allow for movement of water and salts through the root zone, or where there is risk of adverse effects from movement of the leached salts.

In order to reclaim waterlogged, salt-affected soil, the water table must first be lowered and the excess salts leached out. Salts can be removed and prevented from accumulating only if the water table remains deep enough to permit leaching without subsequent re-salinization through capillary rise of the groundwater. Wherever topographic conditions, soil imperviousness or the presence of shallow groundwater prevent adequate drainage from the soil profile, artificial drainage will be necessary. Soil remediation of natural salts under waterlogged soil conditions on agricultural land have shown that shallow drainage, in conjunction with proper irrigation management, has significantly reduced salinity in the upper 30 cm of the soil (Paterson and Harker, 1995).

Artificial drainage should be considered when:

- Depth to top of seasonal high water table or perched water table is less than 2 - 3 m from the surface.
- Sites are in wet areas, wetland areas, depressions or low slope positions.
- The saturated hydraulic conductivity of any layer is < 0.5 cm/hr.

- Sites have potential for a significant amount of salts to leach to groundwater or other receptors (e.g. sandy soil, high water table, high volumes/concentrations of salt, etc.).

To maximize the effectiveness of treatment, a drainage specialist should be consulted to ensure drain depths, spacing, etc. are correct for a particular site. Water diversion projects may require an approval under the Water Act from Alberta Environment. Contact the local Regional Alberta Environment office (Natural Resources Service, Regional Support Branch).

Installation of Drainage

Artificial drainage can be achieved by the installation of subsurface drains. These subsurface drains may consist of slotted plastic pipes, buried vaults or mole drains (subsurface drainage pathways created in fine textured soils with a specialized plough). The drains utilize gravity or a pump to discharge the water to a collector. Saline water collected must be properly disposed. According to Hillel (1980b), drainage from the soil to the drainage network depends on:

- Hydraulic conductivity of the soil (fine textured soils are more difficult to drain);
- Configuration of the water table and relative hydraulic pressure of the groundwater when there is a shallow groundwater tables;
- Depth of the drains relative to the groundwater, if present, and the soil surface;
- Horizontal spacing between the drains and number of drains (drain density) installed;
- Slot size and total open area on drain tubes and diameter of the drains; and
- Rate at which water is added to the groundwater table, if present.

Water will not flow into drains from tension-saturated or unsaturated soils. For water to flow into a cavity or drain, the soils must be saturated. Drain lines are usually placed side by side at equal depth. Various equations exist which propose to determine the optimal depths and spacing of drains in different soil and groundwater conditions. One of the most widely used is the Hooghoudt equation (Hillel, 1980b).

Containment and Disposal

Leachate can be collected through the use of subsurface drains in combination with trenches, bell holes and storage tanks. Drain lines must be laid out in a shallow uniform gradient so that water will flow to the collection point. Laser-assisted plows offer precise depth control when laying drain lines.

Frequent monitoring of the amount of collected water is necessary to ensure that the collected leachate does not overflow or back up into the drain lines. Monitoring drainage water chemistry

(EC and SAR) is necessary to determine appropriate disposal of the leachate. It can also indicate the success in replacing sodium in the soil and leaching of the salts from the soil. Deep well disposal of the leachate may be a viable option, provided the requirements of the Energy and Utilities Board (EUB, 1994) are met.

3.3.2.6 Erosion Protection

Saline areas should not be left bare for extended periods of time, especially where the sites are susceptible to wind or water erosion. Surface covers, such as straw mulches, can be used to protect the soil surface from erosion. Mulches also reduce evaporation and therefore help the soil retain more moisture for leaching.

Revegetation with salt tolerant species before remediation is complete should be avoided, unless sufficient water can be added to account for plant uptake. Plants will use available water, reducing the amount available for leaching. However, plant roots have a beneficial effect on soil structure and revegetation may be desirable on old spills where soil structure has degraded, provided available water is sufficient to meet leaching requirements.

3.3.2.7 Remediation of Salt Contaminated Forest Soils and Wetlands

Upland Soils

Innes and Webster (1978) published a field manual for reclamation of upland boreal forest soils. Some of their conclusions are listed below. Note that their recommendations are based on field research results obtained for the particular brine, soil and site characteristics in their study; other procedures may be required under other conditions. Installation of drainage and collection and disposal of leachate may also be necessary.

- The normal recommendation for cultivated soils is to add gypsum while the salt load is still high. In these field trials, however, the gypsum was added after flushing was completed. The results indicated that these procedures worked well at this location. They reasoned that the dispersion of sodium affected soils occurred to a lesser extent in forested areas; the soils are usually covered with leaf litter, and there is no cultivation to break down surface soil structure.

- The length of time brine is in contact with roots of vascular plants and moss stems is critical. Therefore the concentration of brine must be reduced as soon as possible after a spill by flushing with fresh water. Flush with fresh water only if surface soils are peat, organic leaf litter, or very sandy. Fresh water flushing before replacement of sodium in soils with significant clay content risks causing dispersion and degradation of soil.

- Two flushes are recommended. Salts are removed predominantly from large pores in the first flush. Salts then diffuse from small pores to the large pores and are removed in the second flush.
- In similar environments to the study area flushing should be continued until seepage from the spill area is below 1 dS/m.
- Damage to the environment can be reduced with prompt action after a spill. A contingency plan, equipment and amendments should be readily available for use.

Wetlands

Very little information is available on remediation of salt spills in wetland environments. Remedial approaches must balance physical destruction of natural vegetation with the need to mitigate salt damage to vegetation. Prichard et al. (1985) found that flushing and drainage collection was effective in reclaiming a salt-affected organic soil. Bogs (nutrient poor) and fens (nutrient rich) may respond differently to nutrient imbalances caused by salt contamination as well as calcium amendments used in remediation. For example, *Sphagnum* mosses, the principle ground cover in bogs, may be adversely affected by elevated pH and calcium concentrations (Clymo, 1973).

3.4 Verification of Remediation Success

In order to verify meeting generic or site specific guidelines, confirmatory samples taken after remediation is complete should be collected and analyzed. This may include collection of monitoring information over a period of time. In justifying the samples taken, the person taking the samples should be able to answer the following questions:

- Why was that particular (e.g. location, depth) sample taken?
- How does that sample fit into the overall contaminant distribution and site characteristics (e.g. most severely contaminated area, edge of contaminated area, coarser textured layer, top of seasonal water table)?
- How was the sample taken (methodology)?
- What do the analytical results mean in relation to remediation objectives (e.g. have remediation objectives been met or do monitoring results indicate an improving trend)?

4.0 RISK ASSESSMENT PROCEDURES

Site specific risk assessment is a means of quantifying the likelihood that contamination will have an adverse impact under conditions found at a specific site. Where remediation is required, risk assessment will help identify appropriate remediation targets. In the case of salt contamination, the most common impacts are likely to be on the agricultural capability of soil and on the potability of water.

A risk assessment is based on an evaluation of the potential for receptors to be exposed to the salt contaminated soil or water, and the hazard to the receptors. The risk of impact from salts is related to the exposure of receptors, sensitivity of receptors, and hazard (type and magnitude of effect on receptors). A risk assessment must gather sufficient information on each of these components.

A site-specific risk assessment consists of the following five components:

1. **Problem formulation** involves developing a conceptual model of the possible exposure conditions and contaminant effects on receptors at the site. The conceptual model includes a description of contaminant distribution, movement and concentration in relation to locations and patterns of activity of the receptors.

2. **Receptor characterization** involves identifying the species, communities, habitats, and valued ecosystem components, including surface water, groundwater and soil resources, which are or should be present at the site.

3. **Exposure assessment** describes the pathways by which the receptors may be exposed to contaminants. This information is combined with receptor characteristics in order to estimate the contaminant uptake rate.

4. **Hazard assessment** describes the adverse impacts of the contaminants and the benchmark dose at which these impacts occur.

5. **Risk characterization** compares the benchmark dose with actual dose (estimated during the exposure assessment) and determines whether or not an adverse effect is likely to occur.

Risk assessment can also be used to calculate contaminant concentrations at which no adverse effects are expected. For more information on risk assessment and the development of site specific objectives refer to CCME (1996a, 1996b, 1996c).

4.1 Risk Assessment Conceptual Model

The risk based approach requires a conceptual model to be developed that identifies potential sources, pathways and receptors. The model must take into account probable future conditions at the site. The level of detail of the model depends on the site and contaminant characteristics. Figure 4.1 identifies the most common sources, pathways and potential receptors that may be impacted by dissolved salts in soils and groundwater. Figure 4.2 illustrates, in schematic form, a conceptual model of the potential flow pathways of dissolved salts.

4.1.1 Receptors

Receptors of salt contamination are likely to be plants, livestock, wild animals, fish, humans, soil, groundwater and surface water. Additional receptors may be identified during development of the conceptual model. If it is not possible to take into account all receptors, representatives may be selected with a justification for the selection. A risk based assessment should identify which receptors are of concern on and off the site.

The receptors must include those species that were capable of growing in the affected areas prior to contamination. Revegetation with salt tolerant species may be useful in some stages of remediation, but the site will only meet equivalent land capability when it can grow a comparable range of species, as before contamination. If natural soil salinity existed in the site area prior to disturbance, the range of species that can grow on the control area and on the site may be limited to those that are salt tolerant.

4.1.2 Pathways of Exposure

Pathways of exposure, such as direct contact with vegetation (surface and root zone), leaching to groundwater, or subsurface flow into adjacent soil or surface water and subsequent uptake must be identified (Figures 4.1 and 4.2). The location of salt-affected soil with respect to receptors has a strong influence on potential exposure. Determination of pathways has a predictive element because the salts are very mobile; i.e. future movement of salts to receptors must be considered. A hydrogeological investigation may be necessary to predict future pathways resulting from leaching and groundwater transport.

Figure 4.4.1 Potential Sources, Pathways and Receptors of Dissolved Salt – Development of Conceptual Plan

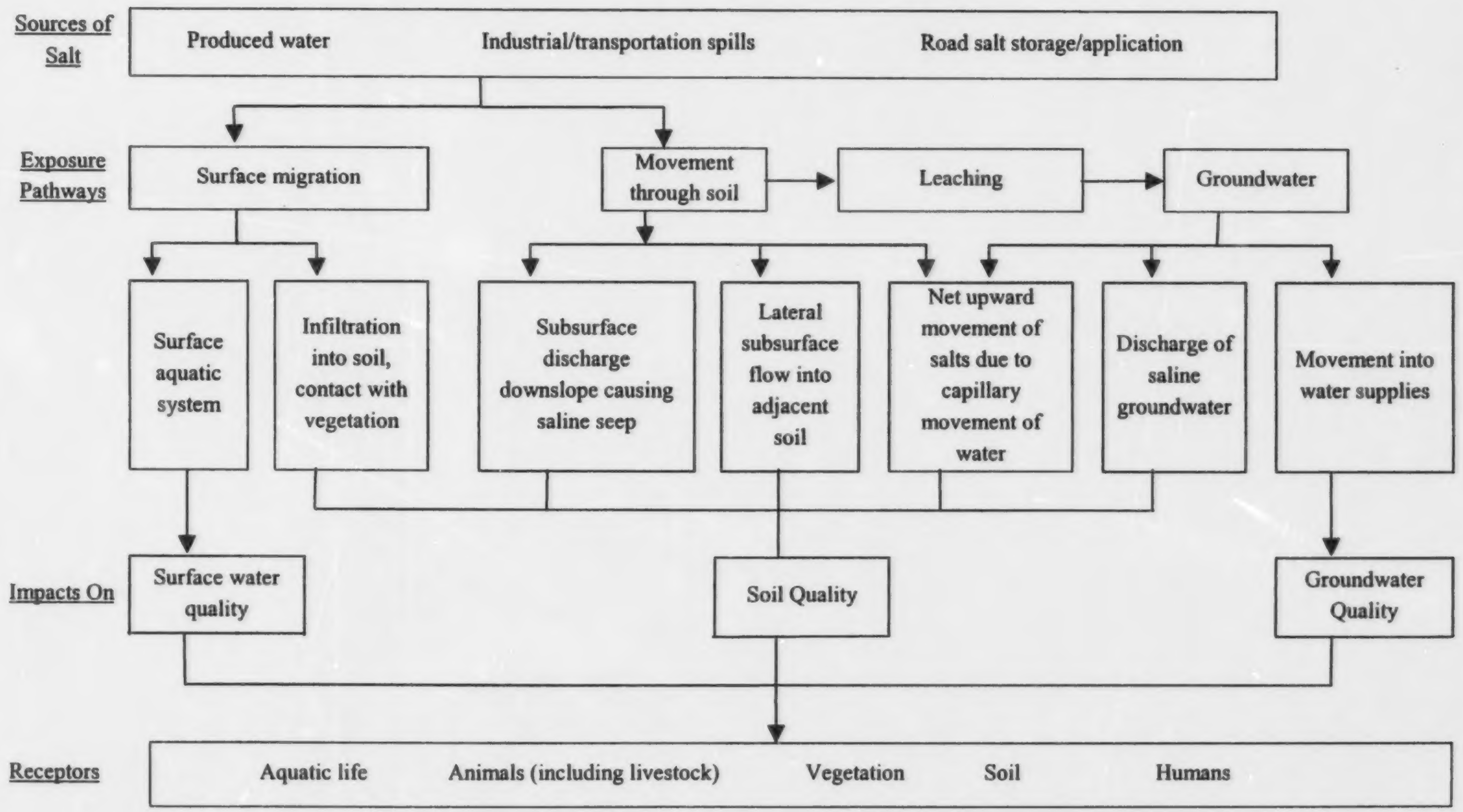
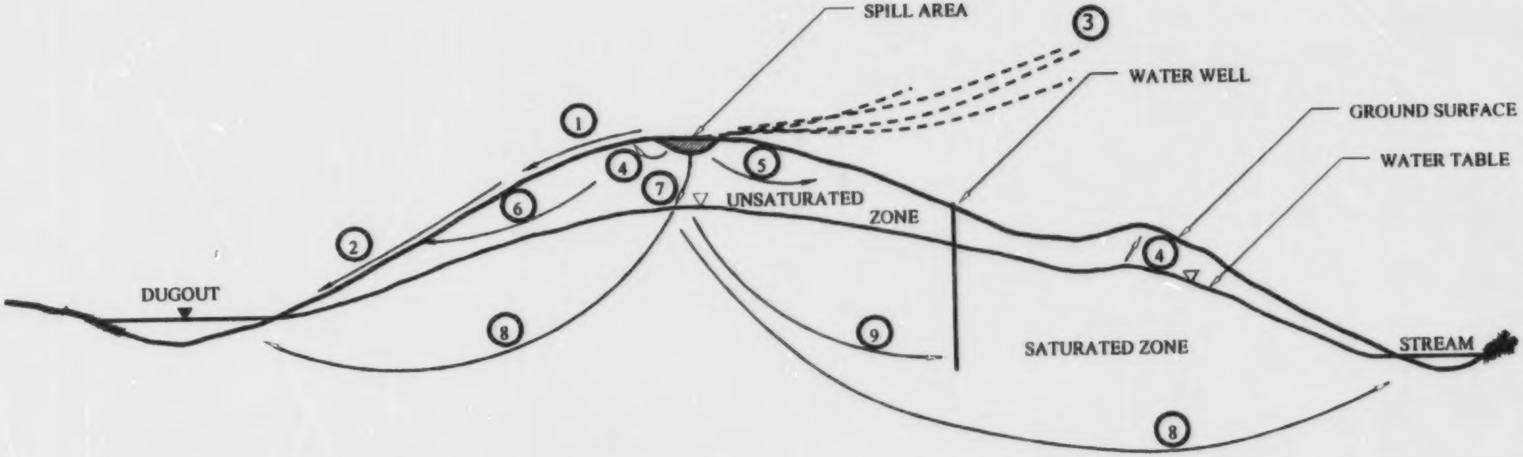

Sources of Salt
Produced water
Industrial/transportation spills
Road salt storage/application
Exposure Pathways
Surface migration
Movement through soil
Leaching
Groundwater
Surface aquatic system
Infiltration into soil, contact with vegetation
Subsurface discharge downslope causing saline seep
Lateral subsurface flow into adjacent soil
Net upward movement of salts due to capillary movement of water
Discharge of saline groundwater
Movement into water supplies
Impacts On
Surface water quality
Soil Quality
Groundwater Quality
Receptors
Aquatic life
Animals (including livestock)
Vegetation
Soil
Humans

Figure 4.4.2 Conceptual Model of Flow Pathways



LEGEND

SURFACE RUNOFF

- ① Adjacent soil and vegetation
- ② Surface aquatic systems (dugouts, steams, lakes, etc.)
- ③ Wind erosion/transport

SUBSURFACE MIGRATION

- ④ Capillary rise
- ⑤ Subsurface migration in unsaturated zone to adjacent soil and vegetation
- ⑥ Saline seep through unsaturated zone
- ⑦ Downward migration into groundwater
- ⑧ Migration with groundwater to discharge area
- ⑨ Migration with groundwater to drinking water supply

4.1.3 Hazard

The level of hazard of exposure to salt will vary with a given receptor. Plant and aquatic species vary in their susceptibility to salinity-related water stress and sodium and chloride toxicity. Sodium hazard to soil varies with soil texture and salinity levels. A risk assessment should address changes in the ionic strength of the soil solution in conjunction with soil SAR, the potential for soil dispersion and the adverse impacts on the soil that may result.

Salinity can result from direct or indirect impacts to the site. Potential sources of direct impact include spills of formation or process water, process wastes (e.g. flare pits) and road salts. An indirect cause of salinity may be increased groundwater recharge from irrigation or other sources, which can result in a raised groundwater table. A near-surface water table can lead to bring water from the capillary fringe to the surface where the it evaporates, leaving behind salts.

4.2 Level of Detail of Risk Assessments

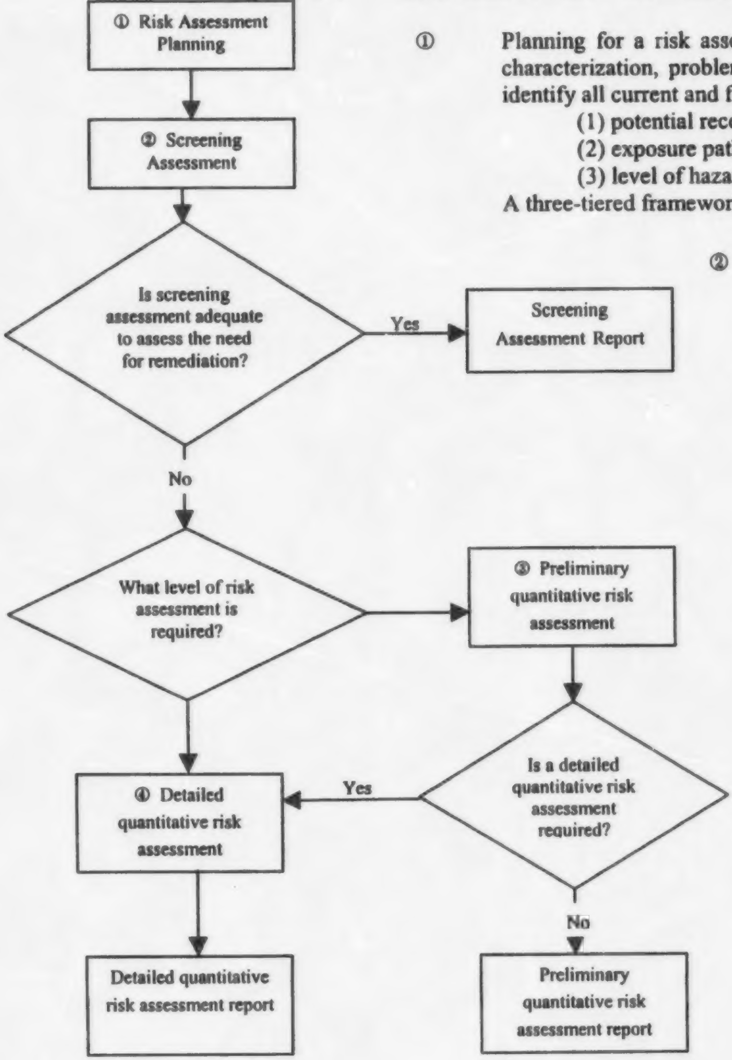
Once the types and degrees of risk have been identified, the level of detail required for a risk assessment can be determined. Figure 4.3 illustrates a three-tiered framework to represent different levels of detail in a risk assessment site evaluation. Each tier represents an increasing level of detail and complexity.

The level of detail, complexity and sophistication needed for a risk assessment depends on the characteristics of the spill, the environmental sensitivity of the site and the potential severity of impact. Level of detail represents a continuum from qualitative to detailed quantitative information, as follows (CCME, 1996a):

- Screening assessment;
- Preliminary quantitative risk assessment; and
- Detailed quantitative risk assessment.

All three levels require the five risk assessment components described in this section. If qualitative assessment cannot characterize the risk of adverse effect on potential receptors with an acceptable degree of certainty, a quantitative investigation is necessary. The level of certainty considered acceptable for terminating a risk assessment must be determined by the professional judgement of the risk assessor in consultation with Alberta Environment. For small spills on low sensitivity sites (low risk of exposure to receptors) a screening assessment may be sufficient, and the initial site investigation may provide sufficient information for an adequate risk assessment.

Figure 4.3 **Risk Assessment – Decisions on Level of Detail (Canadian Council of Ministers of the Environment 1996a)**


① Risk Assessment Planning
② Screening Assessment
Is screening assessment adequate to assess the need for remediation?
Yes
Screening Assessment Report
No
What level of risk assessment is required?
③ Preliminary quantitative risk assessment
Is a detailed quantitative risk assessment required?
Yes
④ Detailed quantitative risk assessment
No
Detailed quantitative risk assessment report
Preliminary quantitative risk assessment report

① Planning for a risk assessment should address communication with Alberta Environment and other stakeholders, site characterization, problem formulation and development of a conceptual model of the site. The risk assessment must identify all current and future:

(1) potential receptors of concern on and off site,
(2) exposure pathways, and
(3) level of hazard and potential for adverse effects.

A three-tiered framework representing sequentially more sophisticated and detailed evaluations is recommended.

② The **screening assessment** is simple, is qualitative or comparative in nature, and relies mainly on literature information and previously collected data. Screening assessment studies are more likely to be descriptive as opposed to predictive. A screening assessment compiles and evaluates existing data; identifies exposure pathways, information gaps, and additional chemicals of concern; refines the conceptual model; and determines if remediation or further risk assessment studies are needed.

③ The **preliminary quantitative risk assessment** is based on a combination of measured site-specific data and previously collected information. There is an increased emphasis on data collection with a focus on the site-specific priority issues. In particular, factors identified as moderate risks in the screening assessment are investigated further. A preliminary quantitative risk assessment should build on the information compiled for the site, and data should be collected to fill significant gaps. If the preliminary quantitative risk assessment does not adequately characterize site and contaminant impact, a detailed quantitative risk assessment must be done.

④ A **detailed quantitative risk assessment** is carried out when further data are needed to reduce the uncertainty about the estimate of risk resulting from a preliminary quantitative risk assessment. Its aim is to produce quantitative predictions regarding current and future risks to receptors due to the presence and migration of salts on and off the site. It may also aim to develop an adaptive process for selecting site-specific, quantitative remediation objectives, which may be revised over time. This level may require more extensive field testing, more complex models, or validation of issues such as community or ecosystem effects, multiple pathways, etc. Computer modeling may be required.

The level of detail and complexity of a risk assessment must suffice to characterize the risk with an acceptable degree of uncertainty (CCME, 1996a).

The level of detail of a risk assessment is related to the uncertainty of characterization of receptors, exposure pathways and hazard. Uncertainty is often related to complexity of the site. Simple situations, such as a small volume of contaminated soil at the bottom of a flare pit, may require only a screening assessment. A screening assessment might also be sufficient where there is a small volume of salt-contaminated subsoil with low levels of salt contamination below the root zone, at a site with little risk of salts moving to receptors (such as groundwater) in a concentration likely to cause adverse effects. More complex situations, with large volumes or areas of salt contaminated soil and higher risk of movement to receptors may require more detailed assessments. More complex situations might include, for example, an old spill site with a large area of contaminated soil, or a site in which a significant amount of salts could migrate into shallow groundwater.

In establishing the level of effort required in a risk assessment, operational boundaries and constraints must be considered. At some point, decisions on logistical boundaries of remediation must be made. These decisions should take into account the level of detail of the risk assessment, the objectives of the assessment, the exposure level and the risk characterization.
The kind of data that are available can determine which risk assessment procedures will be implemented within existing schedule or budget limitations. For example, only a screening level assessment may be possible with existing data; if this level meets the objectives of the assessment, further data collection may not be required. On the other hand, the available data may determine that although receptor characterization is adequate, additional studies are required for exposure and hazard characterization.

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APPENDIX A - BACKGROUND INFORMATION

A1.0 Sources of Salt

A1.1 Produced Water

Brine is water from geological formations that is often produced with hydrocarbons. As oil and gas reservoirs are depleted the proportion of brine produced with hydrocarbons often increases. It is separated from the hydrocarbons at a processing facility and then usually disposed of by injection down a deep well. Salts commonly associated with brine are sulfates, bicarbonates and chlorides of the cations sodium, calcium and magnesium. Sodium chloride is generally the most abundant form of salt in brine.

The composition of the water from geological formations can vary greatly, both between and within formations. It may approach rainwater in composition (total dissolved solids ranging from <10 mg/l to a few tens of mg/l), or range up to saturation with halite (about 150,000 mg/l sodium and 230,000 mg/l chloride) (Hitchon et al., 1998). Table A1 lists minimum and maximum content of selected properties and ions in brine (Brian Hitchon, 1998, personal communication). Table A.2 compares the concentrations of selected ions from seawater, river water and selected brines.

A1.2 Road Salt

Sodium chloride is the most commonly used salt for application to roads, although other salts such as KCl are sometimes used. Salts are released to the environment when spread on roads and from snow dumps and transportation yards where large volumes of salt mixed with sand are stored without adequate provision to prevent leaching and runoff.

A1.3 Excavation of Subsoil Material

Where naturally saline soils occur (see Appendix A2 below) at depth, they may be mixed with non-saline root zone soil during excavation. If the saline material is left within the root zone, it can impair vegetative growth and soil quality.

Table A.1 Selected Properties and Ions of Formation Waters from the Alberta Basin

Parameter	Minimum	Maximum	No. Of Samples
Depth (m)	104.3	3,632.3	689
Temperature (°C)	10	118	689
Na (mg/l)	390	100,800	694
K (mg/l)	5.6	8,800	694
Mg (mg/l)	0	7,800	694
Ca (mg/l)	4	38,700	694
Sr (mg/l)	0.2	1,320	690
Ba (mg/l)	0.04	680	564
F (mg/l)	0.01	22	465
Cl (mg/l)	305	199,510	694
Br (mg/l)	0.5	1,313	662
I (mg/l)	0.3	66	619
SO4 (mg/l)	1	6,444	680
HCO3 (mg/l)	10	7,750	694
pH***	4.29	8.1	666

***calculated at formation temperature and in equilibrium with calcite using SOLMINEQ.88 (computer model)

A1.4 Other sources

Salts are used in a number of manufacturing processes such as wood pulp production, animal hide curing, and chlorine production. Spills and leaks from storage facilities or during transportation can result in contaminated soil and water.

A2.0 Naturally Occurring Saline and Sodic Soils

Saline and sodic soils can result from natural processes as well as spills. Spills may occur on soils that are already naturally saline or sodic. No matter what the cause, excess salinity and sodicity will reduce the agricultural capability and productivity of soil.

Table A.2 Selected Ion Concentrations from Seawater, River Water and Brines

Parameter	River Water[a]	Seawater[a]	Formation Water[a] (Western Canada Basin)	Viking Formation (Swan Hills Field)[b]	Gilwood Formation (Swan Hills Field)[b]	Brine Water From Oil Battery[c]
Cl^{-1} (mg/l)	7.6	19,500	26,920	24,800	132,000	125,000
Na^{+1} (mg/l)	7.0	10,800	14,340	15,00	62,800	47,250
Ca^{+2} (mg/l)	36.0	413	2,210	570	16,100	20,434
Mg^{+2} (mg/l)	7.8	1,300	317	300	2,300	3,687
SO_4^{-2} (mg/l)	31.4	2,700	350	12	150	<3
HCO_3^{-1} (mg/l)	106	-	1,500	300	75	394
Salinity (mg/l)	203	35,334	46,400	-	-	201,567
Electrical Conductivity (dS/m)	<1[d]	-	-	19.6	-	187

[a] Hitchon et al, 1998
[b] Innes & Webster, 1978
[c] CAPP, 1996
[d] Aqualta, North Saskatchewan River, Rossdale (pers. comm. 1998)

Soils that have high soluble salts are classed as saline; soils with a high proportion on the cation exchange complex are classed as sodic; soils high in both high soluble salts and sodium are classed as saline-sodic.

A2.1 Saline Soil

The term >saline soil= is used to describe soils containing sufficient soluble salts to adversely affect the growth of most crop plants. These salts, when dissolved, exist as positively charged cations (e.g. sodium, calcium, potassium, and magnesium) and negatively charged anions (e.g. chloride, sulfate, bicarbonate, and carbonate) in the soil solution. The high salt content of the soil solution in saline soils produces harmful effects in plants by restricting their water uptake. The presence of excessive salts causes plants to go into drought stress prematurely even though substantial water may be present in the soil. The pH of saline soils is generally less than 8.5.

Electrical conductivity (EC; deci-Siemens per metre [dS/m]) is used to express the total dissolved salt concentration in a solution. The electrical conductivity in a solution is related to the total concentration of all dissolved cations and anions. The charged ions are also referred to as electrolytes. An approximate relationship between EC and total electrolyte concentration (TEC) is given by the formula (Sumner, 1993):

$$10 * EC(dS/m) = TEC\ (meq/L).$$

Total dissolved solids (TDS) is a measure (in mg/L) of all dissolved constituents, regardless of the presence of an electrical charge, and usually correlates with EC (Bohn et al., 1985):

$$TDS\ (mg/L) \approx 640 \times EC\ (dS/m)\ .$$

Ionic concentration, total electrolyte concentration, and EC are interchangeably used to represent the concentration of ions in a soil solution.

A2.2 Sodic Soil

Clay particles in soil have a negative electric charge that attracts the positively charged cations in a soil solution. These cations, held on clay surfaces and organic matter, are referred to as adsorbed or exchangeable ions. The negatively charged clay surfaces, along with organic molecules, constitute the cation exchange complex. Sodic soils have high levels of exchangeable sodium on the clay particles' surfaces. A high concentration of exchangeable sodium, coupled with a low overall concentration of salts in the soil solution can induce dispersion and swelling of the clay particles, and result in degradation of soil physical characteristics such as permeability, aeration and structure (see Appendix A4.3). The degree to which dispersion causes degradation of soil characteristics is related to the clay content of the soil (i.e. soil texture).

Sodium concentrations in soil are generally measured by Sodium Adsorption Ratio (SAR), which is an approximate measure of the relative amount of sodium relative to calcium and magnesium in a soil solution. Exchangeable Sodium Percentage (ESP) is also used; it is a measure of the percentage of exchangeable sodium on the cation exchange complex.

Although there is no sharp change in soil properties at a specific SAR (Richards, 1954), a soil with SAR greater than 13-15, or an ESP of about 15, has been traditionally considered to be sodic (Brady, 1990). However, published research and review papers indicate that soil degradation (decreased hydraulic conductivity) can take place below these SAR levels in clay textured soil (Crescimanno et al., 1995; Sumner, 1993). Sumner (1993) states that sodic soil conditions can be exhibited at ESP levels well below those previously used to define sodic soils.

A2.3 Saline-Sodic Soil

Saline-sodic soils are high in both soluble salts and exchangeable sodium. These soils generally limit plant growth largely by their high levels of soluble salt (Bohn et al., 1985). Because soluble salts prevent hydrolysis reactions, the pH of these soils is typically less than 8.5. Leaching of these soils removes soluble salts, resulting in a sodic soil with its associated soil problems. A discussion of the effects of soluble salts and sodium on soil is presented in Appendix A4.3.

A2.4 Alberta Soils

Soils in some areas in Alberta have naturally occurring levels of salt or sodium that are detrimental to plant growth. These naturally occurring concentrations can be higher than those resulting in some salt spill contaminated soils.

The most common naturally occurring salts found in Alberta soils consist of sodium (Na^+), magnesium (Mg^{++}), and calcium (Ca^{++}) ions in combination with sulfate ($SO_4^=$), bicarbonate (HCO_3^-), and to a lesser extent chloride (Cl^-) ions. Sodium and magnesium sulfates are the two most common naturally occurring salts on the prairies. Sodium sulfate is the dominant soluble salt in the east-central and southern regions, whereas magnesium sulfate is more common in the Peace River Region. Bicarbonate and chloride salts are found in lesser amounts accompanying the sulfate salts (VanderPluym and Harron, 1992). In many naturally occurring saline soils, salts are visible as small white or yellow crystals in the soil profile or a whitish appearance of the soil surface.

Most Alberta soils do not have sufficient naturally occurring adsorbed sodium to cause dispersion and poor structure. The exceptions are Solonetzic soils, which have poor soil structure and permeability resulting from high sodium concentrations on the cation exchange complex. These soils are recognized mainly by their columnar structure, hard consistence when dry, and dark organic staining in the B horizon. There are often visible salts in the C horizon. Solonetzic soils are common in east central and southern Alberta, as well as in a few other areas.

Table A.3 compares selected salt related chemical parameters for different soils.

Table A.3 Salt Related Chemical Parameters of Typical Soils in Alberta

Parameter (soluble ions, etc)	Non saline soil (surface 20 cm)[a]	Brine contaminated soil[b]	Brine/ hydrocarbon contaminated soil[c]	Solodized Solonetz-Csk horizon[d]	Solod – Bnt horizon[d]	Solonetz – Bntks horizon[d]	Solodized Solonetz – Csk horizon[e]
Cl^{-1} (mg/kg)	5.9	4270	nd	0.1	Trace	70.9	nd
Na^{+1} (mg/kg)	6.0	2580	3500	160.9	184.9	1425.4	nd
Ca^{+2} (mg/kg)	16.0	341	465	320.6	40.1	40.1	nd
Mg^{+2} (mg/kg)	5.7	80.2	695	267.4	Nd	97.2	nd
SO_4^{-2} (mg/kg)	0.29	9.8	nd	1536.9	432.3	3458.2	nd
Electrical Conductivity (EC) (dS/m)	0.5	25.3	26.8	7.2	1.9	7.8	7.5
Sodium Adsorption Ratio (SAR)	0.1	48.2	24	nd	nd	nd	18.2

a Black Chernozem soil, Lloydminster area; proprietary data
b 25-55 cm depth soil sample on well lease near Edmonton; proprietary data
c oil/brine contaminated Black Chernozem soil, 0-25 cm; CAPP, 1996
d Toogood and Cairns 1978
e McNeil et al 1994.
nd no data

A2.5 Natural Salinization of Soils

Soluble salts in saline soils originate largely from bedrock and glacial drift. These salts rarely become a problem at the location where they are formed. However they are transported by subsurface water movement to discharge areas, where they become concentrated at or near the surface of the soils because of evapo-transpiration.

When excess water percolates through the soil it can dissolve, transport and concentrate salt in downslope areas. Water in excess of crop use, whether it comes from seepage, over-irrigation, or precipitation, can raise the water table locally or downslope. When the water table rises close to the soil surface, the net rate of water movement to the surface by capillary action (Appendix A3) may exceed the downward flow of water. Thus, salts are carried toward the soil surface where the water evaporates and salts accumulate. The potential for this upward movement of groundwater (capillary movement) to reach the surface is dependent on groundwater table depth, soil texture, soil density, soil layering and soil water gradients, and is affected by irrigation, rainfall, consumptive use and evaporation. Depending on site conditions, when the water table is within approximately 2 metres of the surface, there is a possibility of capillary movement of water to the soil surface.

Restricted drainage, presence of a high groundwater table (often related to topography) and low permeability of the soil contribute to the salinization of soils. Low permeability of the soil impedes downward movement of water and may be the result of fine texture, poor structure or the presence of a hardpan (high bulk density layer).

Much additional information on saline and sodic soils and effects on vegetation is available in soil science journals, government agricultural extension publications, soil text books, and salt spill courses and manuals. Some of these are listed in Appendix A5.

A3.0 Movement of Salts in Soil and Groundwater

Salts associated with salt spills are highly soluble, and are easily moved along with the movement of water in the soil (soil solution). Therefore mechanisms that control water movement in soil also control salt movement. This section covers basic principles of subsurface water and salt movement.

A3.1 Water Movement in Soil

Water in a soil solution has a certain pressure potential, largely dependent upon the degree of saturation of the soil. The primary forces driving water movement through a soil are gravity and differences in pressure potential (hydraulic gradient). Pressure potential decreases from saturated conditions to dry conditions, so soil water moves in response to the hydraulic gradient from wet to dry soil.

When water is applied to unfrozen soil, the initial movement of the solution into the soil is determined by the infiltration rate at the soil surface and the hydraulic conductivity of the soil. Infiltration rate is the rate at which water enters the soil surface per unit of soil surface area. Hydraulic conductivity is the rate of flow through a cross section of unit area of soil or geologic material (under a unit hydraulic gradient).

Infiltration at the Soil Surface

Infiltration at the soil surface depends upon the initial wetness of the soil and on the texture, structure and layering in the soil profile (Hillel, 1980a). In general, infiltration is high in the early stages, particularly where the soil is initially quite dry, but tends to decrease over time to a constant infiltration rate.

When water is applied to the surface, the gradient in pressure potential from the wet soil at the surface to the drier soil below is quite high. This gradient and gravity are the driving forces that cause water to percolate downwards. As the deeper soil becomes saturated, the pressure potential gradient decreases and infiltration slows.

Formation of a crust at the soil surface can be a result of the breakdown of soil structure due to excess sodium (Appendix A4.3). The impact of raindrops on the aggregates at the soil surface cause clay dispersion to occur at lower sodium levels than required for dispersion within the soil profile (Sumner, 1993). Thus the infiltration rate which exists at the surface is more sensitive to sodium (due to crust formation) than the hydraulic conductivity in the soil profile. Crusts can significantly decrease infiltration rate at the soil surface. Thus less water moves through the soil profile and leaching of salts is reduced. Also there is a greater risk that the rate of water added to the surface will exceed the infiltration rate and result in runoff and subsequent erosion.

In summary, infiltration rate at the soil surface depends on:

- Time from onset of rain or irrigation - rate is high at first and declines to a constant rate characteristic of the soil profile;
- Initial water content - the wetter the soil, the lower the initial infiltration rate, and the sooner the constant rate will be attained;
- Hydraulic conductivity - the higher the conductivity of the soil, the higher the infiltration rate;
- Soil surface conditions - poor structure and crusting will retard infiltration; and
- Impeding layers in soil profile - may retard water movement - as water infiltrates over time, ultimately it is the layers with the lowest conductivity that control the rate of downward movement.

Typical orders of magnitude of the final, ‘steady’ infiltration rate (for a deeply wetted profile) for various soil textures are shown in Table A4 (Hillel, 1980a).

Table A.4 Typical Orders of Magnitude of Steady Infiltration Rate for Selected Soils

Soil	Steady Infiltration Rate (mm/hr)
Sands	>20
Sandy and silty soils	10-20
Loams	5-10
Clayey soils	1-5
Sodic clayey soils	<1

Hydraulic Conductivity

The rate of movement of water (including saline water from releases) in soil is largely regulated by hydraulic conductivity. Hydraulic conductivity may be measured in any direction. Hydraulic conductivity controls the rate of movement and the distance salt water moves immediately after a release, the potential of salts to move laterally or downwards to receptors (such as groundwater) and remediation procedures (application of irrigation water, leaching and collection of leachate).

Darcy=s law states that the flow of water through soil is in the direction of, and at a rate proportional to the driving force on the water, and that it is also proportional to the ability of the soil to transmit water in that direction (Hillel, 1980b). The ability of a soil to transmit water is referred to as the hydraulic conductivity of the soil. Hydraulic conductivity can vary by several orders of magnitude, depending on total porosity, pore geometry, fluid properties (i.e. viscosity and density) and the degree of saturation.

Total porosity and pore geometry are dependent on soil texture, structure, fracturing, etc. Pore geometry and interconnectivity determines the cross-sectional size and tortuosity of the paths (connected pores) through which the water flows. Hydraulic conductivity generally decreases with finer soil texture and poorer soil structure (e.g. massive structure, sodic columnar structure, Luvisolic blocky structure). Pore size is the main determinant of hydraulic conductivity. Gravelly or sandy soil may have hydraulic conductivity much greater than a clay soil that has small pores, even though clay generally has greater total porosity.

Hydraulic conductivity also depends on the amount of water in the pores. As moisture in the soil pores increases, conductivity increases to maximum under saturated conditions (saturated hydraulic conductivity). A larger amount of water in the pores (and less air) results in a larger cross-sectional area through which the water can flow. Hydraulic conductivity is approximately constant and at its maximum value in saturated soil. In unsaturated soil, hydraulic conductivity decreases with moisture content. Saturated hydraulic conductivity values for sandy soil range from 10^{-2} to 10^{-3} cm/sec and for clay soil range from 10^{-4} to 10^{-7} cm/sec (Hillel, 1980b). Table A.5 illustrates the rate of movement of water at different saturated conductivities.

Table A.5 Approximate Rate of Movement of Water in Saturated Soil[1]

Soil Texture	Saturated Hydraulic Conductivity (cm/sec)	Approximate movement per day
Coarse sandy	10^{-2}	0.2 m/day
Fine loamy	10^{-4}	0.2 cm/day
Clay	10^{-6}	< 1 mm/day

[1] assuming a hydraulic gradient of 0.01 and a porosity of 50%.

Rate of movement of water downward through the soil is significantly influenced by differences in hydraulic conductivity and soil properties such as texture. A soil layer with lower hydraulic conductivity (e.g. a compacted, dispersed or clayey layer) can significantly retard the downward movement of water.

In sodic soils, infiltration rate and downward movement of water can be greatly reduced by crusting at the surface and by lower soil permeability caused by dispersion. The hydraulic conductivity of these soils can be improved with the replacement of sodium by calcium on the cation exchange complex.

Upward Movement of Water in Soil

The pressure potential of soil water decreases as the degree of saturation decreases. Therefore, soil water moves in response to the hydraulic gradient from moist to dry soil (high pressure potential to low). Thus, in addition to moving downwards in response to gravity, soil water can also move laterally, or even upwards, if the force on the water due to the pressure potential gradient is greater than the force on the water due to gravity. Evaporation dries out the soil surface, promoting upward movement of soil water from moist soils below to the drier soils at the surface. Salts dissolved in the soil water move upward along with upward moving soil water. Soil water may evaporate at or near the surface, resulting in concentrated salts in the upper soil.

A3.2 Salt Movement in Soil

Movement of dissolved salts in soil is strongly dependent on water flow direction and velocity. Highly soluble ions such as chlorides, nitrates and sodium move readily with the soil water. Where the dominant direction of water movement is downward, salts will be leached toward the water table. Salts also move through soil water by diffusion and hydrodynamic dispersion. The net effect of the latter two mechanisms is a tendency to equalize the spatial distribution of diffusible components (such as salt) in the water. Dissolved ions tend to diffuse from higher to lower concentration.

Capillary Movement Up From a Water Table - Capillary Fringe

In areas with salt present in the subsurface, a high water table, and a **net upward movement of water** (discharge areas), salts will accumulate at or near the soil surface. The tendency for water to be drawn from the water table toward the soil surface persists as long as the suction head is greater (more negative pressure potential) than the depth of the water table (Hillel, 1980a). This condition occurs particularly in arid and semi-arid regions where evaporation dries out the soil surface. Excessive irrigation in some areas tends to raise the water table and aggravates the salinization problem.

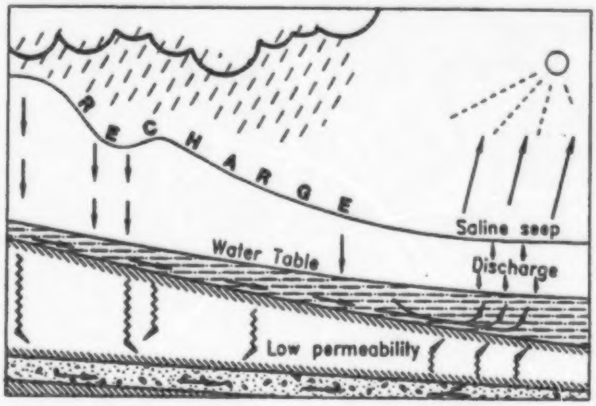
Movement of water upward from a water table is referred to as capillary movement. The capillary fringe is the zone above the water table into which water moves by capillary suction. Saturated soil conditions exist in the capillary fringe. The thickness of the capillary fringe depends on pore size of the soil, which is determined by soil texture and structure. Generally the height of capillary rise is greater in fine textured soils if sufficient time is allowed, and if the pores are interconnected and not too small (as they could be in compacted clay). If the water table is within approximately 2 metres of the soil surface, capillary movement may carry water to the surface, depending on soil texture and structure (Saskatchewan Agriculture, 1987).

Salts are carried upward with capillary rise and become concentrated at the top of the capillary fringe when the water evaporates. If the capillary fringe reaches the root zone, the salt accumulation can impair plant growth. A critical depth can be defined below which there is little risk of upward salt movement into the root zone. The critical depth will be site specific, depending on pore size distribution, salt concentration in groundwater, and other factors (Smedema and Rycroft, 1983; van Hoorn, 1978; Talsma, 1963). Further information on the mechanics of capillary movement of soil water may be found in soil physics texts such as Hillel (1980b).

Lateral Movement of Water and Salts

Two other conditions causing salinization on the prairies are groundwater discharge and side hill seeps. Groundwater discharge occurs when the upward pressure in an aquifer is sufficient to force water to the soil surface. A side hill seep can occur when the water table intercepts the ground surface at the base of a hill. Also, when water moves downward through the soil and then laterally along a sloping, impermeable subsurface layer, it can accumulate salts as it moves. This water may eventually discharge at the surface on a nearby lower slope and cause salinization. In discharge areas, it is difficult to prevent accumulation of salts at the surface without lowering the water table. Figure A.1 illustrates a generalized mechanism of saline seeps (VanderPluym and Harron, 1992).

Figure A.1. Example of Mechanism of a Saline Seep Formation



A3.3 Computer Modeling of Soil Salinity and Plant Growth

A number of models have been developed to make predictions about soil salinity and resulting plant growth under different management conditions. Some are very sophisticated models (i.e. Cardon and Letey, 1992a, 1992b; Grant, 1995; Letey et al., 1985), require detailed input variables and are designed primarily for research purposes. Some simpler models with less data requirements include Watsuit (Rhoades et al., 1992); or a model discussed by Ayars et al. (1977). The LEACM-C model and Watsuit are described by Tanji (1990). Researchers at Alberta Agriculture, Lethbridge, have had good success with the LEACM-C model (Gary Buckland, personal communication, Dec. 1996).

A4.0 Effects of Salt on Soil, Vegetation and Groundwater

High concentrations of salt and sodium can have environmental impacts on soil, vegetation, surface water, and groundwater. The most commonly occurring effects will likely be on agricultural capability of soil and potability of water. However, other components of the ecosystem such as wetlands may also be adversely affected.

Typical environmental impacts associated with excess salt in soil and surface or groundwater are:

- **Degraded chemical soil quality and impaired vegetation growth**. All natural waters, including those in the pores of soil, contain dissolved salts and thus possess a degree of salinity. A salinity problem in soil develops if salts accumulate to concentrations that cause reductions in plant growth. At those concentrations, the salt in the soil solution interferes with the plant uptake of water. Generally, as the concentration of salt increases, vegetation growth problems associated with salt accumulation increase.

- **Degradation of soil physical properties is caused by sodium,** which is not easily removed from the soil and is potentially a long-term contaminant. Excess sodium in soil can be caused by salt spills that have a high sodium chloride content, which causes soil physical problems such as poor permeability, poor structure/tilth and crusting at the soil surface, thus degrading the soil as a growth medium for plants.

- **Degraded surface or groundwater quality**. In addition to impairing or preventing the growth of vegetation, excess levels of salt render water resources unsuitable for use. Spills causing elevated levels of salts (including chloride and sodium) can adversely affect the quality of our drinking water, freshwater aquatic systems, agricultural water used for irrigation, livestock, recreational water, industrial water supplies.

A4.1 Initial Effects of a Salt Water Release on the Soil

When a salt water spill occurs, a concentrated solution of ions, generally dominated by positively charged sodium ions and negatively charged chloride ions, enters the soil. As the salt water mixes with and displaces some of the water in the soil pores, the ion concentration in the soil solution increases greatly. The high relative concentration of the sodium ions in the soil solution results in the sodium ions displacing many of the other ions on the soil's cation exchange sites. The negatively charged chloride ions are not adsorbed to the cation exchange sites and are more easily leached from the soil.

A4.2 Effect of Soil Salinity on Vegetation

The initial adverse environmental effect of a salt water release is usually the effect of increased soil salinity on vegetation. Plant growth in saline and saline-sodic soils is generally limited by the high soluble salt concentrations in the soil. Salt in soil water reduces or prevents uptake of water by plants because of increased osmotic pressure; this reduces or prevents plant growth. Excess ions in the soil solution can also disrupt the nutritional and metabolic processes of plant. For example, cereals and some other plants can experience calcium deficiencies when the Na/Ca ratio in soil exceeds a certain threshold level (Maas, 1996). Many woody species and legumes are sensitive to chloride toxicity and can experience reductions in growth even when water deficits are not limiting (Marschner, 1995). Sodium toxicity is less widespread but can affect some cereals such as wheat (Marschner, 1995).

Plants growing on saline soils may appear stunted and have thickened leaves with a dark green colour. Substantial reductions in plant growth can also occur without appreciable changes in plant appearance. Plants are most severely affected by salinity in the early stages of growth, from germination to the four leaf stage. Different plant species vary in their tolerance to saline conditions. McKenzie (1998) observed that some special crops or horticultural crops have low salinity tolerances. In addition, EC of 3 to 8 dS/m causes major reductions in growth of salt sensitive crops, and causes some reduction of yield in most other crops.

Tables A.6 and A.7 list various plants and their relative tolerance to salt. A qualitative indication of native plant salt tolerance can be found in Gerling et al. (1996). Information on the salt tolerance of boreal forest species can be found in Edwards and Blauel (1975), Innes and Webster (1978a), Edwards (1985), Maynard et al. (1997), Renault et al. (1998), and Renault et al. (1999).

Certain plant species can indicate the presence of salts in soil. The following groups of native plant indicator species are listed in order of decreasing salt tolerance (Alberta Agriculture, 1995):

- Red Samphire
- Nuttal=s Alkali Grass, Sea Blite
- Salt Grass, Prairie Bullrush, Seaside Arrowgrass
- Orache, Foxtail, Kochia
- Tufted white prairie aster
- Gumweed

Table A.6 Threshold ECs and Yield Loss due to Salinity[1]

Crop	Threshold EC (dS/m)	% Loss in Yield/(dS/m)
Annual Field Crops		
Beans	1.0	20.0
Rye	1.4	10.8
Fababeans	1.6	9.6
Corn	1.7	12.0
Flax	1.7	12.0
Wheat	<2.5	12.0 - 16.0
Barley	4.0	15.0
Sugar beets	7.0	5.9
Forage Crops		
Red clover	1.5	12.0
Alsike clover	1.5	12.0
Alfalfa	2.0	7.3
Crested wheatgrass	7.5	6.9
Tall wheatgrass	7.5	4.2

[1] Adapted from Stepphun and Wall (1996) and the United States Dept of Agriculture Salt Tolerance Databases (USDA, May 5 2000). Annual crops based on seedling sensitivity where possible.

Table A.7 Relative Sensitivity to Soil Salinity of Selected Plants[2]

Degree of Salinity Tolerated (EC)	Annual Field Crops	Forage Crops
Non to slightly saline (0-4 dS/m)	Peas Canola	Timothy
Moderately saline (4-8 dS/m)	Mustard Oats Safflower Sunflower	Reed canary Meadow fescue Intermediate wheatgrass Bromegrass Sweet clover
Severely saline (8-16 dS/m)	Barley may produce some crop, but best suited plants are tolerant forages	Russian wild ryegrass Slender wheatgrass Salt meadow grass
Very severely saline (16-20 dS/m)		Altai wild ryegrass Levonns alkaligrass Alkali sucaton Puccinellia distans

[2] adapted from Holm (1982), Saskatchewan Agriculture (1987) and Alberta Agriculture (1995)

Steppuhn (1997) investigated seed germination, plant emergence and *initial* survival of different plant species on Saskatchewan soils ranging in salinity from 2 to 50 dS/m. The study did not consider advanced plant growth, maturity and seed production. Seed mixtures recommended for emergence and initial survival for reclamation or pasture use in saline soils were listed as follows:

Wet soils: Creeping Rooted Alfalfa, Fleet Meadow Bromegrass, Courtenay Tall Fescue and/or Adanac Slender Wheatgrass, Garrison Creeping Foxtail, Orbit Tall Wheatgrass;

Dry Soils: Creeping Rooted Alfalfa, Chief Intermediate Wheatgrass and/or Adanac Slender Wheatgrass, Kirk Crested Wheatgrass, Tetracan Russian Wild Ryegrass; and

Native perennial: Green Needlegrass, Slender Wheatgrass or Awned Wheatgrass, Nuttall's Saltgrass.

Note that these mixtures were recommended based on initial survival in saline soil. In a remediation situation other factors may affect choice of seed mix, such as area specific considerations, erosion control, land use, and undesirable invasive species.

Examples of species suitable for moderately to very saline native areas in Alberta (depending on location) include, western wheatgrass, beardless wildrye, slender wheatgrass, basin wildrye and northern wheatgrass (Wark et al., no date).

A4.3 Soil Structure and Effects of Excess Sodium and Dispersion

Importance of Good Soil Structure

Soil structure is an important soil property because it affects other soil properties such as water retention, drainage and aeration that are critical in providing good growth conditions for plants. Soil with good structure has a range of aggregate sizes, with a corresponding range of pore sizes.

Large macro pores between soil aggregates contribute to improved drainage and aeration, whereas smaller micro pores within the aggregates contribute to good water retention. Good soil structure also promotes lower soil bulk density, good tilth (workability), and a good physical growth medium for plant roots and root elongation.

Effects of Excess Sodium and Dispersion on Soil Structure

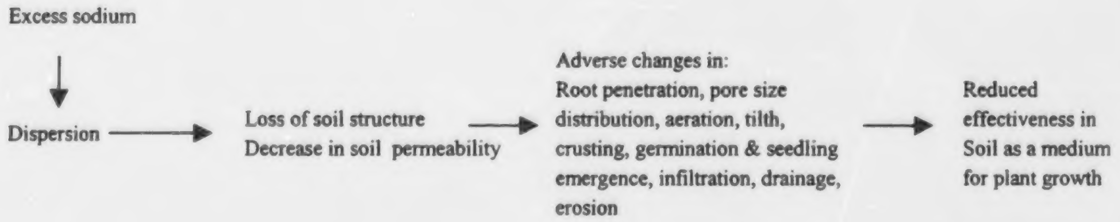
High exchangeable sodium concentrations can cause dispersion and swelling of clay particles resulting in degradation of soil structure (breakdown of soil aggregates), and surface crusting. Surface crusting retards infiltration, and causes greater surface runoff, thus decreasing the amount of water available for plants and promoting erosion.

When clay particles disperse, they plug water flow channels within the soil. Dispersion and swelling of clay particles decreases hydraulic conductivity of the soil and results in poor drainage, excess moisture and inadequate aeration. These soil conditions result in poorer plant growth.

Poor soil structure and crusting caused by clay dispersion results in less favourable soil conditions for germination, seedling emergence, plant root penetration and plant root elongation. In general, at a given sodium adsorption ratio, the permeability of fine textured soils is adversely affected to a greater degree than coarse textured soils (Richards, 1954).

High levels of sodium on clay surfaces are a more permanent problem than the high salt content, because exchangeable sodium usually persists after soluble salts are removed. Figure A.2 illustrates how sodium adversely effects soil properties and vegetation.

Figure A.2 Adverse Effects of Sodium on Soil (arrows lead from cause to result)


Excess sodium
Dispersion
Loss of soil structure
Decrease in soil permeability
Adverse changes in:
Root penetration, pore size distribution, aeration, tilth, crusting, germination & seedling emergence, infiltration, drainage, erosion
Reduced effectiveness in Soil as a medium for plant growth

Aggregate Formation, Dispersion and Flocculation

Aggregate formation occurs when soil conditions favour the flocculation (coming together) of clay particles. Therefore soil conditions which favour flocculation are desirable. Once flocculated, the particles in the aggregates near the soil surface are bound together (stabilized) by organic molecules. Clay particles can disperse in soil that has high levels of sodium in the soil solution and on the cation exchange complex, and low ionic concentration of the soil solution, as explained in the following sections. Important concepts in the following discussion are EC, SAR, and ionic concentration of the soil solution.

Flocculation (Coagulation) and Aggregate Formation in Non-Sodic Soils

Clay particles have a net negative charge and thus tend to repel each other. Dissolved ions in the soil solution are hydrated (the ions are surrounded by water molecules held in place around the ion by electrostatic forces). In non-sodic soils (soils with a low SAR) calcium ions are more abundant than sodium ions in the soil solution and on clay surfaces. The positively charged, hydrated calcium ions are attracted to negatively charged clay particles and are adsorbed to clay surfaces. Hydrated calcium ions are small enough to move close to the clay surface. They neutralize the negative charge of the clay at the surface so that the clay particles do not repel each other. Under these conditions, the clay particles flocculate, and stability of soil aggregates is promoted.

Conditions Favourable to Dispersion and Breakdown of Aggregates in Sodic Soil

In sodic (high SAR) soil, sodium ions are adsorbed onto the cation exchange complex in significant amounts, displacing other ions, including calcium and other plant nutrients. A hydrated sodium ion has a larger radius than a hydrated calcium ion in the soil solution. Therefore, hydrated sodium ions cannot move as close to the clay surface as hydrated calcium ions. With many sodium ions adsorbed onto clay surfaces, the negative charge on the clay particles is not neutralized near the clay surface, thus causing the clay particles to repel each other and disperse rather than flocculate. The electronegativity of clay particles, and their repulsion and dispersion in sodic soil (high SAR) can be reduced by replacing the sodium on the clay particles with other cations such as calcium.

Suppression of Dispersion in Saline-Sodic Soils with High Ionic Concentration (EC) of the Soil Solution

The most important factor in determining adverse impacts of sodium on soil is the relationship between exchangeable sodium concentration and total electrolyte concentration (total cations and anions [EC]) in the soil solution. High EC suppresses clay dispersion caused by high exchangeable sodium levels (Sumner, 1993). In effect, soil salinity tends to counteract the effect of exchangeable sodium on soil structure (Sposito, 1989). In saline-sodic soils, although sodium is adsorbed to the clays in significant amounts, dispersion does not occur as long as the ionic concentration of the soil solution is high enough to counteract the effect of the sodium.

However, when the ion concentration falls below a critical concentration necessary to maintain flocculation (the critical flocculation [or coagulation] concentration), dispersion of clay particles will result. This critical flocculation concentration of the soil solution, below which dispersion occurs, varies with different soils.

Precipitation or irrigation of saline-sodic soil with fresh water can lower the overall ionic concentration of the soil solution. This leaching removes soluble salts more rapidly than it removes exchangeable sodium, causing conversion to a sodic soil and dispersion of the clay. When the ion concentration of the soil solution falls below a critical concentration, the sodium cations on clay particles cause dispersion. As a result, soil structure breaks down resulting in lower soil permeability. Figure A.3 illustrates a generalized relationship between ion concentration (EC), SAR, and dispersion (Curtin et al., 1995). It can be seen that as SAR increases, a higher ionic concentration (EC) in the soil solution is necessary to prevent dispersion. If EC falls below the critical concentration for a given SAR, dispersion will occur.

Figure A.3 Dispersive Behaviour of Saskatchewan Soils in Relation to SAR and EC (from Curtin et al., 1995)

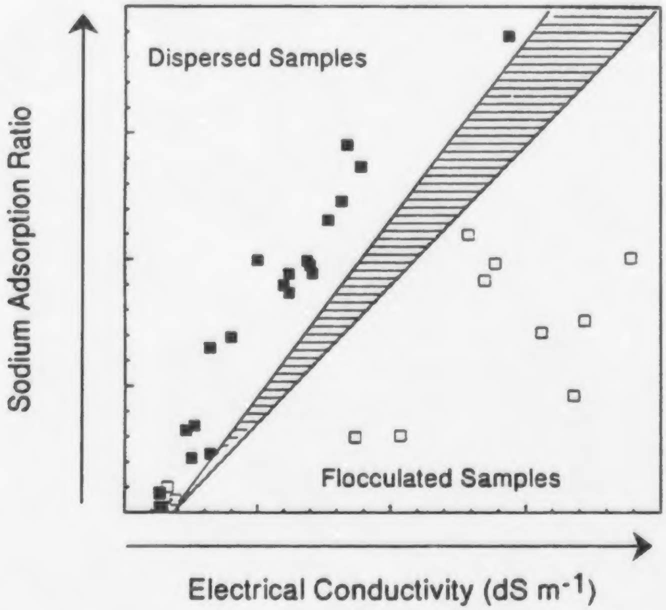
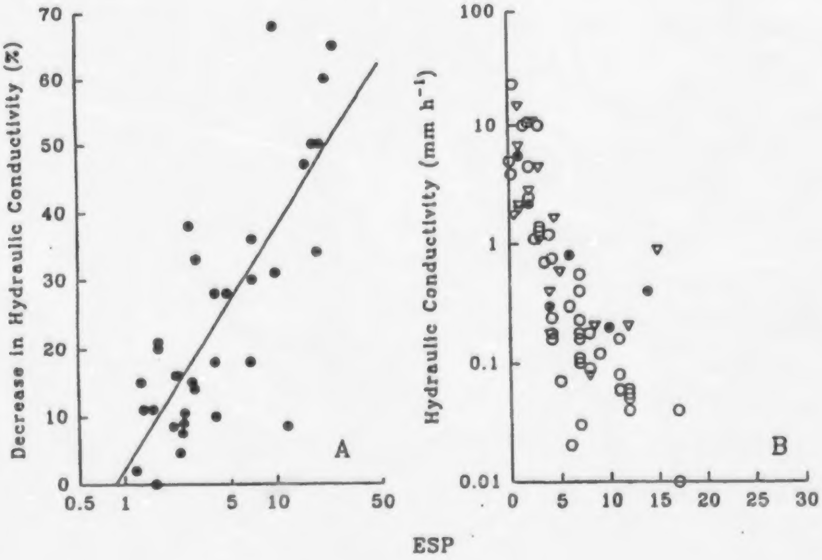


Figure A.4 **Reduction in Hydraulic Conductivity Caused by Leaching Soils that have Various Exchangeable Sodium Percentages (ESP) with Tap Water (A-South African Soils, B-Australian Soils)**



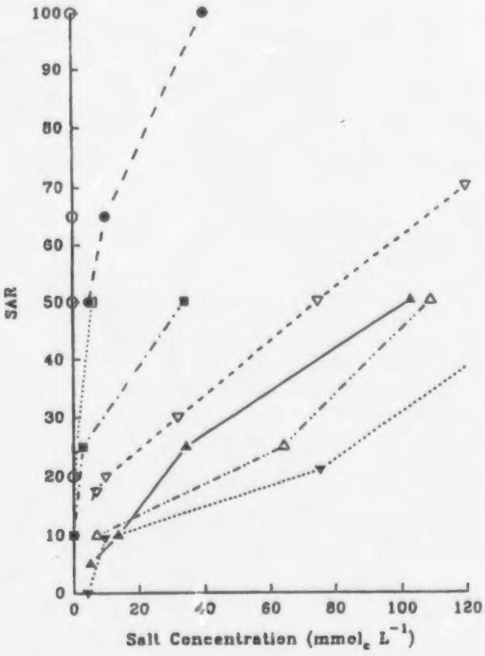
For a more complete discussion of dispersion resulting from sodium adsorption and an explanation of the diffuse double layer on clay surfaces, please refer to texts on soil chemistry (e.g. Bohn et al., 1985).

Effects of Sodium on Hydraulic Conductivity

Figure A.4 illustrates the reduction in hydraulic conductivity in soils with high levels of sodium that have been leached with fresh water (Sumner, 1993).

Figure A.5 (Sumner, 1993) illustrates the combined effect of SAR and salt concentration (EC) in affecting dispersion, and a resulting decrease in hydraulic conductivity. For each soil there is a unique critical concentration of ions at which a stable hydraulic conductivity is maintained for a particular SAR. To avoid dispersion and maintain hydraulic conductivity at a given value, the ion concentration must increase with higher levels of SAR.

Figure A.5 **Combinations of Salt Concentration and SAR that Produce a 25% Reduction in Hydraulic Conductivity in Selected (Non-Canadian) Soils**



A4.4 Remediation of Saline-Sodic Soil by Replacement of Exchangeable Sodium with Calcium

Flushing a saline-sodic soil with fresh water will cause the soil to disperse if salt concentration (EC) is lowered to below the critical level. A fresh water flush should not be used as the initial treatment for leaching of the salts unless the critical concentration is known for the soil undergoing treatment and the drainage water EC is carefully measured. Dispersion will severely retard movement of water through the soil, especially in medium and fine textured soils, making remediation difficult. Recommended remediation procedures are discussed in Section 3.3.

A4.5 Soil Nutrients and pH

Sodium and chloride can displace other nutrient ions from the soil solution and cation exchange sites, and lower the nutrient supply. In addition, increased pH can adversely affect the availability of plant nutrients. Upon leaching with fresh water, some of the exchangeable sodium in the soil hydrolyzes and forms sodium hydroxide. The sodium hydroxide may react with carbon dioxide to form sodium carbonate, with the result that the soil may become strongly alkaline (pH > 8.5).

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GLOSSARY

A Horizon: A mineral horizon formed at or near the surface in the zone of removal of materials in solution and suspension, or maximum in-situ accumulation of organic carbon, or both.

Acid Soil: A soil with a preponderance of hydrogen ions (and probably aluminum) compared to hydroxyl ions. Specifically, soil with a pH value of less than 7.0; for most practical purposes (i.e. plant growth), a soil with a pH value of less than 6.6.

Adsorption: The electrostatic attraction of ions or compounds to a surface. Soil colloids (clay and organic molecules) adsorb large amounts of ions and water. Nutrients in solution (ions) carrying a positive charge become attached to (adsorbed by) negatively charged soil particles.

Aeration, soil: The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is very similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain a much higher percentage of carbon dioxide and a correspondingly lower percentage of oxygen than the atmosphere above the soil. The rate of aeration depends largely on the volume and continuity of pores within the soil.

Aggregate, soil: A group of soil particles cohering in such a way that they behave mechanically as a unit. Mineral soil particles (sand, silt, clay) held in a quasi-stable clump or mass, known as an aggregate, and often stabilized somewhat by a cementing agent, such as organic molecules. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are large aggregates produced by tillage.

Alkaline soil: Any soil whose pH is greater than 7.0.

Aquifer: an underground water-bearing formation that is capable of yielding water.

B Horizon: A mineral horizon characterized by one or more of the following:
1. An enrichment in silicate clay, iron, aluminum, or humus.
2. A prismatic or columnar structure that exhibits pronounced coatings or staining associated with significant amounts of exchangeable sodium.
3. An alteration by hydrolysis, reduction, or oxidation to give a change in colour or structure from the horizons above or below, or both.

C horizon: A mineral horizon comparatively unaffected by the pedogenic processes operative in A and B horizons, except gleying and the accumulation of carbonates and soluble salts.

Capability assessment: An assessment of the pre-disturbance capability of the affected area for some use such as agriculture or forestry, as determined by reference to a representative off-site control area.

Capillary fringe: A zone just above the water table in which the pores are saturated or nearly saturated, and the pressure potential is less than atmospheric. Also called the tension-(negative pressure potential) saturated zone. The thickness of the capillary fringe depends upon the size distribution of pores.

Cation: An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation exchange capacity (CEC): The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. Soil clays and organic matter have a relatively large number of negative charge sites, which retain cations in dynamic equilibrium with the soil solution. The number of cation positive charges retained by 100 grams of soil is called the cation exchange capacity.

Coarse texture: The texture exhibited by sands, loamy sands, and sandy loams – except very fine, sandy loam. A soil containing large quantities of these textural classes.

Crust: A thin, hard, brittle layer of soil that forms on the surface of some soils when they are dry. Crusts are often caused by the breakdown of soil structure at the soil surface and subsequent formation of thin layers.

deciSiemens/metre (dS/m): This is the internationally accepted unit of specific conductance (or electrical conductivity) which is numerically equal to mmhos/cm.

Disperse: (1) To cause soil aggregates to separate into the individual component particles. (2) To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water. Dispersion in soil is the reverse process to aggregation. When freshwater is applied after a saltwater spill, it dilutes and leaches out salts in the soil solution leaving mostly sodium cations to balance electrically the cation exchange sites. The combination of low levels of salinity and a predominance of sodium cations causes clay particles to repel each other and migrate into pore spaces thereby clogging pores.

Dispersed soil: Soil in which the clay has dispersed. A dispersed soil consists of discrete soil particles that are not bound together into aggregates or structural peds. The soil macropores become clogged with soil particles and greatly restrict water and air movement into and through the soil.

Dissolved material: All material which passes through a filter having a pore size of 0.45 µm.

Dissolved solids: A term that expresses the quantity of dissolved material in a sample of water, either the residue on evaporation, dried at 180°C, or, for many waters that contain more than 1,000 ppm, the sum of determined constituents, generally reported in mg/L.

Dry-weight percentage: The ratio of the weight of any constituent of a soil to the oven-dry weight of the soil (constant weight at 105 °C).

Electrical conductivity (EC): EC is a measure of the ability of a substance to conduct electricity measured in dS/m (see deciSiemens/metre). It is directly related to the total concentration of all dissolved cations and anions (electrolytes), and is used to express the magnitude of the total dissolved salt concentration in the soil solution.

Electromagnetic Meters (EM): An indirect (remotely sensed) measure of soil salinity can be obtained using geophysical instruments. EM meters measure the apparent electrical conductivity of the soil, which is directly related to salt content. Measurements are taken from at or near the ground surface, and are useful for initial delineation and determination of variability of the soil EC and salinity.

Equivalent; equivalent weight: The molecular weight (in grams) of an ion divided by its ionic charge.

Evapotranspiration: The loss of water from a soil by evaporation and plant transpiration.

Exchange capacity: The total charge of the adsorption complex active in the adsorption of ions.

Exchangeable cations: Cations on cation exchange sites or in the soil solution that can participate in the cation exchange process in soil. The most common exchangeable cations in soils are calcium, magnesium, sodium, potassium, aluminum and hydrogen. Other exchangeable cations include ammonium, iron, manganese, copper, zinc, and other positively charged dissolved ions in the soil. Exchangeable cations are in dynamic equilibrium between the soil solution and adsorption on cation exchange sites.

Exchangeable sodium percentage (ESP): The extent to which the adsorption complex of a soil is occupied by sodium. Amount of exchangeable sodium expressed as a percentage of total exchangeable cations. It is expressed as follows:

$$\text{ESP} = \frac{\text{Exchangeable sodium (meq/100g soil)}}{\text{Cation exchange capacity (meq/100g soil)}} \times 100$$

Field capacity: The percentage of water remaining in the soil 2 or 3 days after the soil has been saturated and free drainage has practically ceased. Usually expressed as a percentage of its oven-dry weight, or volume.

Fine texture: The soil texture of soil consisting of or containing large quantities of the fine fractions, silt and clay. The texture exhibited by the soil texture classes of clay, sandy clay, silty clay, clay loam, and silty clay loam soils.

Flocculate: The tendency of clay particles to move towards each other due to electrostatic forces. To aggregate or clump together individual tiny soil particles, especially fine clay, into small groups or granules. The opposite of deflocculate or disperse.

Formation Water: Water present in a water bearing formation under natural conditions as opposed to introduced fluids (such as drilling mud).

Freshwater: Water having less than 1,000 mg/L dissolved material.

Gleyed soil: Soil that formed under poor drainage, resulting in the reduction of iron and other elements in the profile and in gray colours and mottles.

Granular structure: Soil structure on which the individual grains are grouped into spheroidal aggregates with indistinct sides. Highly porous granules are commonly called crumbs. A well-granulated soil has the best structure for most dryland crop plants. This type of structure is commonly found in the top horizon (A horizon) of grassland soils.

Hardpan: A hardened or cemented soil layer in the B or lower A soil horizon.

Hydraulic conductivity: The rate of flow of water moving through a cross section of unit area of soil or geologic material, under a unit hydraulic gradient. In saturated materials, saturated hydraulic conductivity is a constant of proportionality in the Darcy equation and is dependent on material properties (grain size and pore space) and on fluid properties (density and viscosity). The rate of flow of water in soil varies from very slow (less than 0.1 cm/hr) to very rapid (more than 50 cm/hr).

Hydraulic gradient: Change in the total hydraulic head divided by the change in distance in a given direction in a groundwater flow system.

Infiltration: The downward entry of water into the soil surface.

Infiltration rate: A soil characteristic determining or describing the maximum rate at which water can enter the soil surface under particular conditions. It has the units of velocity (e.g. cm/sec).

In-situ remediation: Remediation of contaminated soil or water "in-place" in a manner that does not require the contaminated material to be excavated.

Leachate: A solution obtained by leaching, such as water that has percolated through soil containing soluble substances.

Leaching: The removal of materials in solution from the soil by the downward movement of water.

Medium texture: Intermediate in texture and properties between fine-textured and coarse-textured soils. Includes the textural classes loam, silt loam, very fine sandy loam or silt.

Native Plant: A plant that is indigenous to a particular region. Aplant that was in Alberta prior to Euro-American settlement.

Parent material: The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of a soil has developed by pedogenic processes.

Pedon, soil: A three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relations.

Perched groundwater: Unconfined groundwater that is separated from an underlying body of groundwater by an unsaturated zone and a confining layer. The perched zone of saturation may be either permanent, where recharge is frequent enough to maintain a saturated zone, or temporary, where recharge is insufficient.

Permeability: The readiness with which a porous medium (e.g. soil) transmits water or other fluids. It is dependent on grain size, pore size, fracture size and orientation. Unlike hydraulic conductivity it is not dependent on fluid viscosity and density.

pH, soil: The negative logarithm of the hydrogen-ion activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass electrode or indicator at a specified moisture content or soil-water ratio and expressed in terms of the pH scale (see reaction, soil).

Pore space: The total space not occupied by soil particles in a bulk volume of soil.

Porosity: The volume percentage of the total bulk of material not occupied by solid particles.

ppm: Part(s) per million. A measure of concentration of a substance in a solid, liquid, or gas. In solids, ppm equates to milligrams per kilogram (mg/kg) and in liquids to milligrams per liter (mg/L).

Produced water: Water extracted from the ground during oil production processes. Produced water is often, but not always, high in salts and usually contains some hydrocarbons.

Profile, soil: A vertical section of the soil extending through all its horizons and into the parent material.

Quality assurance/quality control (QA/QC): A system of procedures, checks, audits and corrective actions used to ensure the quality of work performed. QA/QC protocols can be utilized during any phase of a project.

Reaction, soil: A measure of the acidity or alkalinity of a soil expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline. The degrees of acidity and alkalinity (expressed as pH values) are as follows:

Extremely acid	below 4.5
Very strongly acid	4.5 to 5.0
Strongly acid	5.1 to 5.5
Medium acid	5.6 to 6.0
Slightly acid	6.1 to 6.5

Neutral	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	9.1 and higher

Saline-sodic soil: (1) A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and also containing appreciable quantities of soluble salts. (2) Commonly defined as a soil in which the exchangeable sodium percentage (ESP) is greater than 15% (SAR greater than 13) and the conductivity of the saturation extract (EC) is greater than 4 dS/m.

Saline soil: A non-sodic soil containing sufficient soluble salts to impair its productivity. The conductivity of the saturation extract is greater than 4 dS/m (at 25°C) and the pH is usually less than 8.5.

Salinity: A term used to describe the amount of salts in a material. The U.S. Geological Survey has assigned terms for degrees of salinity for waters with the following dissolved solids concentration ranges:

Slightly saline	1,000 to 3,000 mg/L
Moderately saline	3,000 to 10,000 mg/L
Very saline	10,000 to 35,000 mg/L
Briny	over 35,000 mg/L

Saturated Paste: A mixture of soil and water in which all soil pores are just filled with water. In undersaturated soil, deionized water is added to a soil sample with minimal mixing until all soil pores are filled with water and there is negligible air in the pores. Mixing is minimized to retain natural pore size distribution as much as possible and to minimize expansion of expandable clay minerals such as smectite and vermiculite. The saturated paste moisture content is useful as a reference because it represents the actual concentrations and ratios of dissolved constituents which are available for uptake by plant roots.

Saturated Paste Extract: Soil-pore water containing dissolved constituents which has been removed from a saturated paste for analysis.

Saturation percentage: The percent of soil-pore water weight to dry soil weight of a saturated paste.

Sodic soil: Commonly considered as a soil that contains an exchangeable sodium percentage (ESP) of 15% or more (SAR of 13 or more).

Sodium adsorption ratio (SAR): The empirical mathematical expression developed as an index of the sodium hazard in soils. The concentrations of sodium, calcium, and magnesium are expressed in meq/L:

$$\text{SAR} = \frac{[\text{Na}]}{\sqrt{\dfrac{[\text{Ca}]+[\text{Mg}]}{2}}}$$

Soil Separates: Mineral particles less than 2 mm in equivalent diameter and ranging between specified size limits. The names and sizes (in mm) of separates recognized are as follows:

Very coarse sand	2.0 to 1.0 mm
Coarse sand	1.0 to 0.5 mm
Medium sand	0.5 to 0.25 mm
Fine sand	0.25 to 0.10 mm
Very fine sand	0.10 to 0.05 mm
Silt	0.05 to 0.002 mm
Clay	less than 0.002 mm

Specific conductance: A measure of the ability of water to conduct an electrical current. It is the reciprocal of the electrical resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specific temperature. The standard measurement is expressed in microSiemens per centimeter at 25°C, abbreviated µS/cm. Specific conductance is related to the type and concentration of ions in solution and can be used to approximate the dissolved-solids concentration in water.

Structure, soil: The arrangement of primary soil particles into compound units or peds (aggregates). The peds are characterized and classified on the basis of size, shape and degree of distinctness. The principal forms of soil structure are as follows: *platy* (laminated), *prismatic* (vertical axis of aggregates longer than horizontal), *columnar* (prisms with rounded tops), *blocky* (angular or subangular), and *granular*. *Structureless* soils are either *single grained* (each grain by itself, as in dune sand) or *massive* (the particles adhering without any regular cleavage, as in many hardpans).

Subsoil: The soil material beneath the topsoil (A horizon); includes the B and C soil horizons. Roughly, the part of the soil profile below plow depth.

Surficial deposits: Unconsolidated residual, alluvial or glacial materials lying on the bedrock.

Texture, soil: The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are *sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay* and *clay*. The sand, loamy sand, and sandy loam classes may be further divided by specifying "coarse," "fine," or "very fine." (See soil separates.)

Tile drain: Concrete, plastic, or ceramic pipe placed at suitable depths and spacings in the soil or subsoil to provide water outlets from the soil.

Till: (1) Unstratified glacial drift deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion. (2) To plow and prepare for seeding; to seed or cultivate the soil.

Tilth, soil: The physical condition of the soil as related to tillage, seedbed preparation, seedling emergence, and root penetration.

Total dissolved solids (TDS): Mineral material suspended or dissolved in solution which passes a standard glass filter and 0.45 μm filter and does not evaporate below 180° C. TDS is generally used as a gross indictor of the mass of dissolved salts in a solution, but the analytical method is subject to interferences from colloidal material.

Transpiration: Loss of water vapor through a plant's stems and leaves to the atmosphere.

Vadose Zone: The zone containing water under less than atmospheric pressure including soil water, intermediate vadose water, and capillary water. The zone is limited above by the land surface and below by the water table.

Water table: The boundary surface between the vadose zone and the groundwater; the surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

Wetland(s): Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, fens and other similar areas.